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ABSTRACT

This booklet describes the results of NASA's Viking spacecraft on Mars. It is intended to be useful for the teacher of basic courses in earth science, space science, astronomy, physics, or geology, but is also of interest to the well-informed layman. Topics include why we should study Mars, how the Viking spacecraft works, the winds of Mars, the chemistry of Mars, experiments in relativity, and the future of the Viking spacecraft. An appendix includes suggestions for further reading, classroom experiments and activities, and suggested films. (BB)

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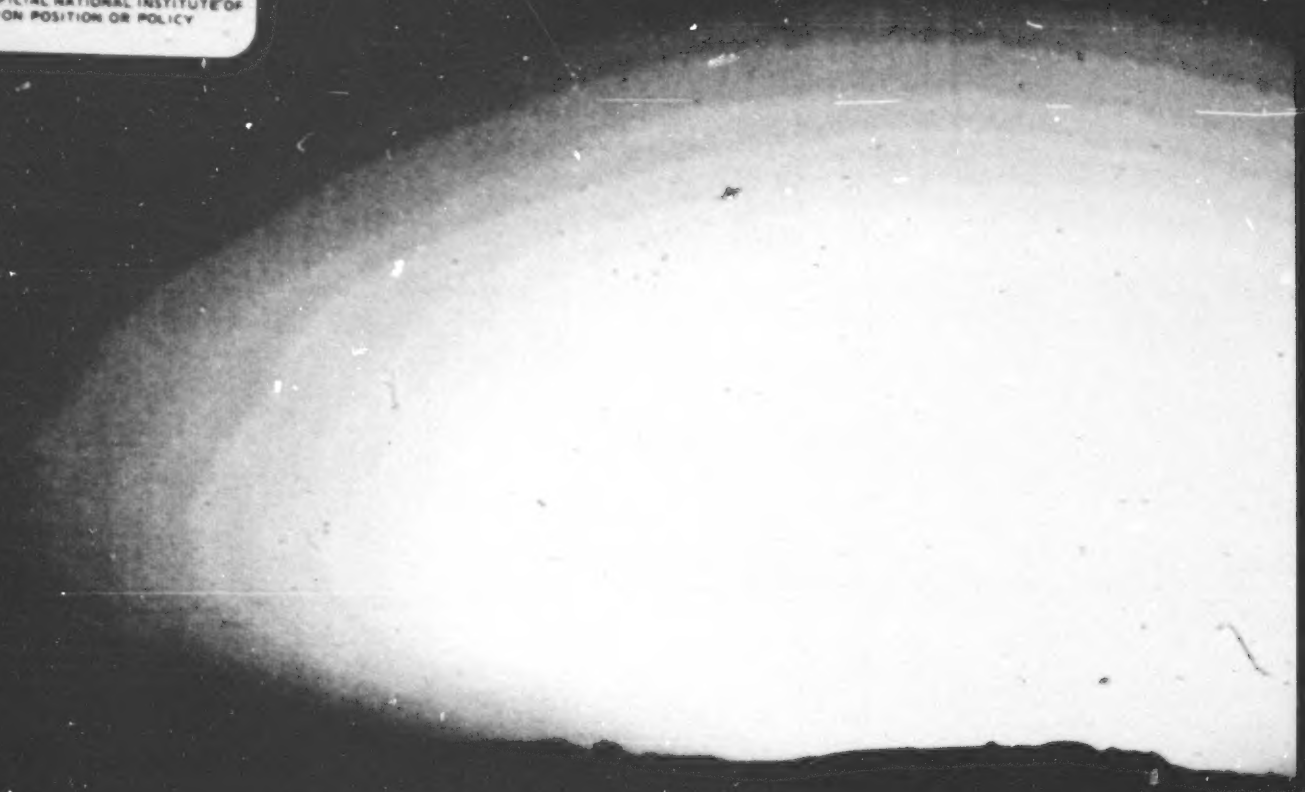

Mars: The Viking Discoveries

SE 025 193

Mars: The Viking Discoveries

by

Bevan M. French
Chief, Extraterrestrial Materials Research Program
Office of Lunar and Planetary Programs
Office of Space Sciences, NASA

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Space Administration

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Cover photo: *Twilight on Mars; from Viking 1 Lander, processed by computer.*

Inside front cover: *Dawn on Mars; Viking 1 orbiter photo found early-morning fog filling this network of canyons on a high Martian plateau.*

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Preface

Mars: The Viking Discoveries is the 17th NASA educational publication to outline the results of NASA's research activities in space sciences.

Prepared in a format that will be useful to the teacher of basic courses in Earth science, Earth-space science, astronomy, physics, and geology, they are also written in a style that will appeal to the well-informed, intellectually curious layman.

The author, Dr. Bevan M. French, is a geologist who has studied Moon rocks and ancient terrestrial meteorite craters for more than 10 years. In 1973 he helped discover a Brazilian impact crater 25 miles in diameter and 150 million years old. He now manages NASA's program for scientific research on meteorites, lunar samples, and other kinds of extraterrestrial materials, as Chief, Extraterrestrial Materials Research Program, Office of Space Science. His program is also helping NASA plan ahead for the return of rocks from yet another world—Mars—so that scientists can find out directly what the Red Planet is really like.

For assisting the author with helpful advice, comments, and criticism, we thank the following: Dr. Richard S. Young, Director, Planetary Biology and Quarantine, Office of Space Science, NASA; Gerald G. Goff, Program Scientist, and Walter Jakobowski, Manager, Viking Program, Office of Space Science, NASA; Dr. Harry Herzer, Senior Specialist, NASA Aerospace Education Services Project and faculty associate, California State University, Chico; Ms. Carolyn P. Schotter, Teacher of Earth Science, Falls Church High School, Fairfax County, Virginia; and Ms. Jeanne Hewitt, Department of Geology, The George Washington University. For extensive editing and revision, we express appreciation to Ms. Mary-Hill French.

October 1977

National Aeronautics and Space Administration
Washington, D.C.

The New Arrival

Exactly 7 years after astronauts first landed on the Moon, a new inhabitant arrived on Mars. On July 20, 1976, a top-shaped object dropped from its orbit hundreds of kilometers above Mars and streaked downward into the late afternoon Martian sky. About 40 kilometers above the surface of the planet, the thin air began to grip and slow the capsule. At an altitude of 6 kilometers, a huge parachute unfurled, a protective shell broke away, and the metallic object inside began to drop to the ground more slowly. At an altitude of 1.7 kilometers, three rocket engines fired downward, slowing the spacecraft even more. The parachute was cut loose, and the object settled gently to the ground. The rocket engines immediately shut down. The Viking 1 Lander had arrived on Mars with no more shock than a terrestrial skydiver landing in the center of his target.

Instantly the computer that had guided the spacecraft on its journey sent a message to Earth that said essentially: "I am here. I am down safely. I am beginning my work." Earth was more than 321 million kilometers (200 million miles) away, and even at the incredibly fast speed of light (300,000 kilometers per second), it was almost 20 minutes later, 5:12 A.M., Pacific Daylight Time, before the Lander's message reached the Viking Control Center at the NASA Jet Propulsion Laboratory in Pasadena, California. When the applause and congratulations began on Earth, Viking 1 already had been studying Mars for 20 minutes. Moments later, Earth's TV screens began to show the first pictures of Viking 1's footpad, firmly planted on the soil of Mars (Figure 1). A new era in our exploration of the Red Planet had begun.

Figure 1. Mars at Close Range. *Tiny Martian pebbles appear in sharp detail in this first picture ever taken on the surface of Mars. Even after being transmitted for 320 million kilometers (200 million miles), the picture is so clear that the observer seems to stand on Mars beside the Viking 1 Lander. One of the Lander's footpads (lower right) rests firmly on a surface made of fine soil and scattered rocks. Large rock (upper center) shows triangular faces that may have been cut by wind-driven sand. Another rock is dotted with small dark pits that possibly were formed by gas escaping from once-molten lava. The picture was taken with a camera that scanned the scene vertically, line by line, from left to right, completing the picture in about 5 minutes.*

Why Mars?

Mars has been in humanity's thoughts since astronomy began. The Babylonians first began to follow the motions of what to them was a wandering red light in the sky, and they named it Nergal after their god of war. Later, the Romans, honoring their own war-god, gave the planet its present name.

A century ago, as the first large telescopes were trained on Mars, observers saw that the planet had a reddish surface, white polar caps, an atmosphere, clouds, and changing patterns of light and dark that might be vegetation on its surface. It seemed to be an Earthlike planet on which life could exist, and some astronomers claimed to see long lines of canals made by intelligent beings. Fiction writers, therefore, needed little encouragement to populate Mars with a wide variety of creatures: philosophical canal builders, leathery monsters who invaded Earth, and a variety of humanoids with human traits of good and evil.

The Space Age methodically removed the basis for much of this kind of romance about Mars. No canals could be seen at close range, and their appearance was explained as optical illusions that had affected Earthly astronomers. The Martian atmosphere proved too thin to breathe, and there was very little water. These discoveries only increased our curiosity about the real nature of Mars and its relation to the other worlds we know. The discoveries did not rule out the possibility that some form of life might exist on the distant planet. Mars was neither entirely dry and airless like the Moon, nor watery and teeming with life like the Earth. What was Mars really like, and what could it tell us about the Earth and the Moon?

Exploration of the solar system had earlier been established as a top NASA goal for the period after Apollo. The program was aimed at a better understanding of the solar system's origin and evolution, the origin of life, and the planetary processes that affect life on Earth. Because Mars, of all the planets, most resembled the Earth and appeared the most likely to harbor some form of life, it was given top priority for scientific study.

As spacecraft observed the planet in closer and closer detail, we discovered that Mars is not uniform. The early flybys (Mariner 4 in 1964 and Mariners 6 and 7 in 1969) had produced photos of a heavily cratered surface that looked as dead and static as the surface of the Moon. But the photographs and maps obtained from Mariner 9 in 1971, as it orbited Mars for about a year, showed that the planet is actually a two-part world.

The southern half of Mars, which the first Mariner spacecraft had looked at, seems much like the surface of the Moon: ancient, inactive, and still heavily cratered by an intense meteorite bombardment that may have occurred during the planet's earliest years.

The northern half of Mars is more Earthlike: younger appearing, geologically active, and perhaps still changing. In this part of Mars the Mariner 9 pictures showed huge volcanoes, great fields of lava, and cracks and fractures in the crust. Most surprising, and most exciting to scientists, were huge canyons and

winding, braided channels that seemed to have been scoured by floods of running water, although no liquid water can be seen on the surface of Mars.

By the early 1970s, Mars had been recognized as an "in-between" world, partly like the Earth, partly like the Moon, yet unique in many ways.

Viking to Seek Answers

The Viking mission would make a more thorough study to answer some of the questions raised by Mariner 9. For example, how old are the huge volcanoes that Mariner 9 had discovered on Mars? It was clear that Mars, like the Earth and Moon, showed evidence of internal heat and volcanic activity. But the Moon has been dead and quiet for more than 3 billion years, since the last floods of lava poured across its surface to form the lunar "seas." The Earth, on the other hand, has been active for the same length of time and is still active today. If the volcanoes of Mars are old, then Mars may be a dead world like the Moon. If the volcanoes are young (and to geologists, a few hundred million years is "young"), then Mars may still be an active planet like the Earth.

The winding channels carved across the Martian surface are another mystery revealed by Mariner 9. If these channels were cut by flood waters, then where has all the water gone? Is Mars now in an ice age like those that once chilled the Earth? Was Mars' water now frozen away underground, waiting for a slight warming to bring it rushing forth again? The further study of Mars might show us how the Earth had started its long history of volcanic activity, and we might even learn how climatic changes and ice ages begin and end.

Moreover, where there are heat and liquid water, there may be life. "How did life start?" and "Is there life elsewhere?" are basic questions that we continue to ask as we explore other planets. The scorched and waterless Moon has yielded no trace of life. On Earth, the records of the origin of life have been erased by the development and activities of later plant and animal life forms. On Mars, where the environment for life is neither as harsh as the Moon's nor as generous as the Earth's we might find, still preserved, the answers to how life came into being. We might even find life itself, answering one of our oldest speculations. Whether Viking detected a humanoid or invisible microbe, the discovery of any Martian life would put us forever in a new relationship to the universe around us.

The Viking Spacecraft

The Viking Mission to Mars thus combined two major goals: to study the atmosphere and geology of the entire planet, and to analyze its soil and search for life in two specific locations. Each of the two Vikings launched toward Mars in 1975 was a double spaceship. One part, the Orbiter, would circle Mars continuously, photographing the surface of Mars and analyzing its atmosphere from hundreds of kilometers above the planet. The other half, the Lander, would go down to the surface of Mars, carrying a battery of instruments to probe directly around the landing site. Once down, the Lander would never leave. The Vikings would not return to Earth with a load of Martian rocks and soil. Instead they would radio back to Earth their discoveries about the atmosphere, chemistry, quakes, soil, and, perhaps, the life of Mars.

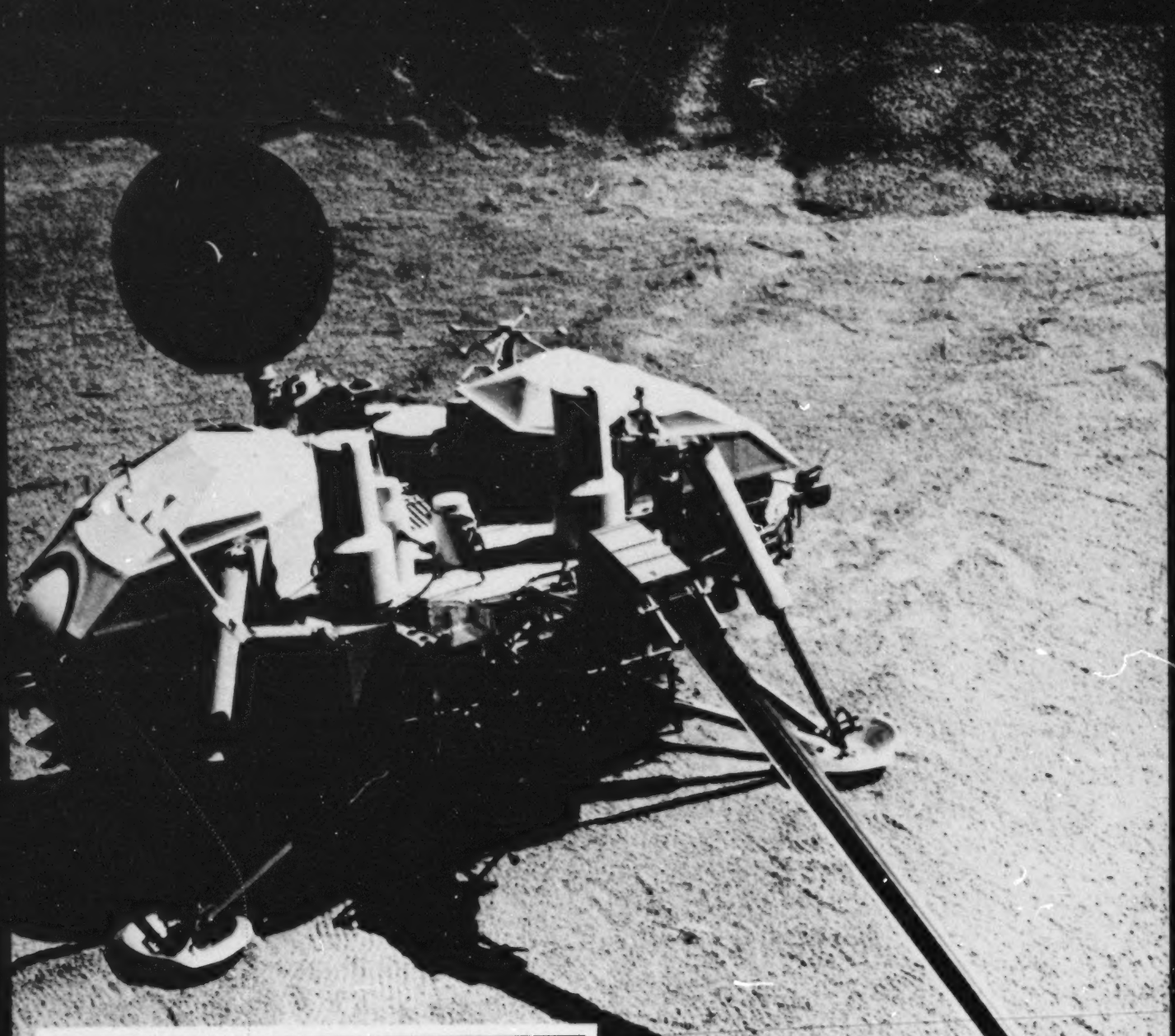
The landing of Viking 1 on the surface of Mars was a complicated and ambitious undertaking, more difficult in some ways than landing astronauts on the Moon. Engineers knew that, at the moment of landing, Mars and Earth would be so far apart that communications between the Viking and its Earth-bound human controllers would take about 20 minutes for a one-way trip. At such distances, there is no possibility of direct intervention if anything goes wrong. Once the computer on the Viking spacecraft was given the order to land, the landing went ahead automatically, and the people on Earth could only wait and hope.

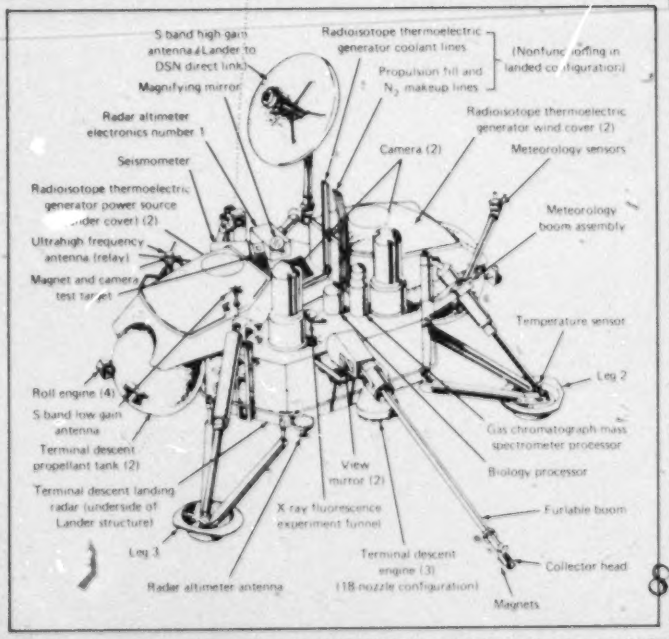
Considering these difficulties, it was not surprising that Viking 1 was actually the fourth attempt to land a spacecraft on the surface of Mars. Two Soviet spacecraft, Mars-2 (1971) and Mars-6 (1973), apparently crashed while attempting to land. A third Soviet spacecraft, Mars-3 (1971) soft-landed safely but stopped operating after less than 20 seconds on the surface.

The Viking mission had two unique and important features designed to make the landing successful. First, the landing area was to be carefully photographed and inspected while the spacecraft stayed in orbit around Mars. In addition, the actual landing could be postponed until an acceptable site was found. Viking 1 spent a month circling Mars while the cameras in the Orbiter portion photographed possible landing sites in great detail and transmitted the photographs back to Earth where scientists examined them for rough ground, boulders, and other possible hazards.

The Viking photographs were sharper and more detailed than anything obtained during the earlier Mariner missions. Landing sites that had been considered safe because they seemed smooth and level in the Mariner 9 pictures suddenly displayed

Figure 2. A Viking Robot Ready for Mars. *A full-size working model of the Viking Lander sits on a simulated Martian surface at the NASA Jet Propulsion Laboratory. This spacecraft, about 1.5 meters (5 feet) across and about 0.5 meters (1.5 feet) high, weighs about 890 kilograms (1 ton). The soil sample collecting arm stretches about 3 meters (10 feet) to the lower right. The cameras are the vertical cylinders, each with a vertical black slit. The disk, top rear, is the S-band high-gain radio antenna that transmits to Earth the camera pictures and scientific data. Equipment and instruments are identified in the accompanying diagram.*




S band high gain antenna (Lander to DSN direct link)
Magnifying mirror
Radioisotope thermoelectric generator coolant lines
(Nonfunctioning in landed configuration)
Propulsion fill and N_2 makeup lines
Radar altimeter electronics number 1
Seismometer
Radioisotope thermoelectric generator power source (under cover) (2)
Ultrahigh frequency antenna (relay)
Magnet and camera test target
Radioisotope thermoelectric generator wind cover (2)
Camera (2)
Meteorology sensors
Meteorology boom assembly
Temperature sensor
Leg 2
Roll engine (4)
S band low gain antenna
Terminal descent propellant tank (2)
Terminal descent landing radar (underside of Lander structure)
Leg 3
Radar altimeter antenna
View mirror (2)
X ray fluorescence experiment funnel
Terminal descent engine (3) (18 nozzle configuration)
Gas chromatograph mass spectrometer processor
Biology processor
Furlable boom
Collector head
Magnets

deep gullies, scattered craters, and rugged outcrops of rock—no place to land a spacecraft which had only 22 centimeters (8 ½ inches) of ground clearance. While the photographs were being scanned, the large radio telescopes at Arecibo, Puerto Rico, and Goldstone, California, bounced radar waves off Mars, using the radar reflections to measure the roughness of the planet's surface in different regions. First one landing site was rejected, and then another. Finally, a new site was located, photographed, scanned with radar, and found acceptable, and Viking 1 descended to a perfect landing in a level rolling region called the Plains of Chryse. A little more than a month later, after a similar thorough check of a more northern region of Mars, the Viking 2 Lander made an equally flawless landing on the Plains of Utopia. Two Landers sit on the surface of Mars, while two Orbiters circle overhead, photographing the planet and relaying back to Earth the news of what the Landers find.

The Landers on the surface of Mars are far more complex than any automatic spacecraft launched before. Even if the Landers had never left Earth, their design and construction would still be an impressive technological achievement. Each lander looks like a cluttered six-sided workbench with three legs (Figure 2) but it contains the equivalent of two power stations, two computer centers, a TV studio, a weather station, an earthquake detector, two chemical laboratories (one for organic and one for inorganic analyses), three separate incubators for any Martian life, a scoop and backhoe for digging trenches and collecting soil samples, and miniature railroad cars for delivering the samples to the laboratories and incubators. Equipment that would normally fill several buildings had been designed in miniature to fit on a spacecraft less than 3 meters (10 feet) across. Furthermore, to avoid contaminating Mars with Earthly bacteria, the entire spacecraft was sterilized by heating it to temperatures above the boiling point of water. Each Lander, and all of its 1 million separate parts, had to survive a number of major crises: the sterilization heating, the shock and vibration of launch, a one-year, 400-million mile trip through interplanetary space, the passage through Mars' atmosphere, and the landing on its surface. No wonder there were heartfelt cheers from the scientists and engineers when Viking 1's first pictures began to appear!

The Landers are so well designed that it is often possible to fix them when things go wrong. When the sampling arm on Viking 1 got stuck, a carefully-planned series of commands from Earth freed it, and the cameras then showed that a small pin which had caused the trouble had fallen free to the ground. Later, when the arm stuck again, this time in an extended position, a different series of commands brought it safely back into the spacecraft. Each of these "repairs" was a carefully-planned operation. Each set of commands was first tested on a duplicate Viking Lander sitting on a simulated Martian surface at the NASA Jet Propulsion Laboratory, and the cameras on the real Viking were used to check the progress of the "repairs" at every step.

With the minor troubles corrected, the Landers even took on new tasks that had not been planned before the landing. After digging up samples of exposed soil, the Lander's sampling arm was used to push large rocks aside and to collect samples of the protected soil beneath them (Figure 3).

A Viking's-Eye View

The safe landing of Viking 1 immediately established one basic fact about Mars: the planet's surface is strong enough to support a heavy machine. The Lander rested firmly on a rolling plain strewn with rocks, and the cameras on the Lander began almost immediately to transmit back to Earth the first views of the Martian landscape.

Viking's cameras stood about 1.6 meters (5 feet) above the ground, and their view of Mars was much like what a person standing in the same place would see. The two cameras could be operated independently to provide panoramas covering almost a full circle around the Lander. They could be operated together to produce stereo pictures from which the shape of the surrounding surface could be accurately measured (Figure 4). Most of the pictures were black-and-white, but different detectors inside the cameras were sometimes used to provide pictures that reproduced the actual hues of the Martian surface.

The first pictures showed firm soil and scattered rocks immediately beneath the Lander. As the cameras looked out to the horizon, they photographed a gently rolling red landscape that could almost have been a desert scene in the American Southwest. The reddish gray soil was dotted with rocks of all sizes. The colors of the rocks varied from dark gray to light gray to slightly reddish (Figure 5). Some rocks showed up in great detail, and many were filled with bubbles. These rocks looked like the lavas produced by erupting gas-rich volcanoes on Earth, and scientists think that the bedrock on which both Vikings have landed is made up of ancient Martian lava flows.

The Viking cameras also saw wind-produced features that have familiar counterparts in Earth's deserts. Although the atmosphere of Mars is thin, its winds are still strong enough to blow dust and fine sand across the surface. There are dunes of light-colored sand, and detailed pictures of the dunes revealed finer ripples within them (Figure 6). There are places where the wind apparently scoured out the fine soil, revealing flat masses of

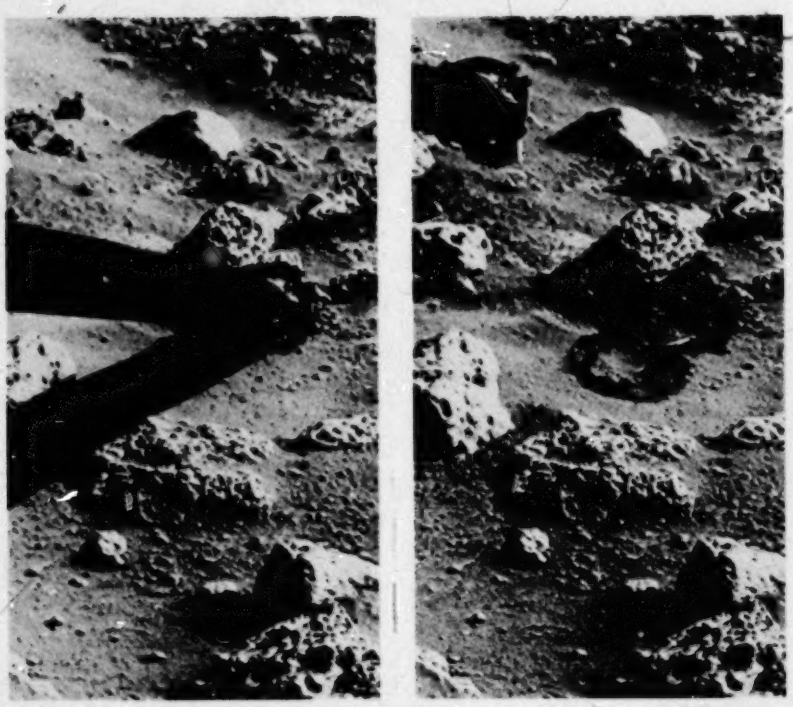


Figure 3. "Mr. Badger" Gets a Nudge. *Controlled by scientists back on Earth, the sampling arm on the Viking 2 Lander reaches out to push aside a large porous rock and to collect a sample of the protected Martian soil beneath it. Because of its shape, the rock was informally christened "Mr. Badger" after a character in Kenneth Grahame's book, The Wind in the Willows.* The Martian "Mr. Badger" is about 25 centimeters (10 inches) long and weighs several pounds.

Figure 4. Mars in 3–D *These two images of the same scene, one taken by each camera on the Viking 1 Lander, can be combined, by using a pocket stereo viewer, into a single 3-dimensional view that shows the rolling Martian terrain and the shapes of the numerous boulders. (When looking at the images with a stereo viewer, concentrate on a small object like a rock. Move the viewer around until the two images of the rock come together. Then you should see the landscape in 3–d.)*

Figure 5. A Summer Day's Work on Mars. *Traces of human exploration already show on the red surface of Mars. Two trenches dug by the soil sampling arm of the Viking 1 Lander appear as short black smudges (left), and the soil near the bottom of the picture that appears cracked and pitted was disturbed by the rocket exhaust blast at touchdown and by the impact of the footpads. The soil sampling arm and scoop is at right center; arm (lower left) holds a brush for cleaning off magnets. Light and dark rocks can be seen. The dark rock to the right of the trenches is about 25 centimeters (10 inches) across. The apparent horizon is about 100 meters (330 feet) away and may be the rim of a small impact crater. Boulders 1 and 2 meters (3 and 6 feet) across are visible in the distance.*

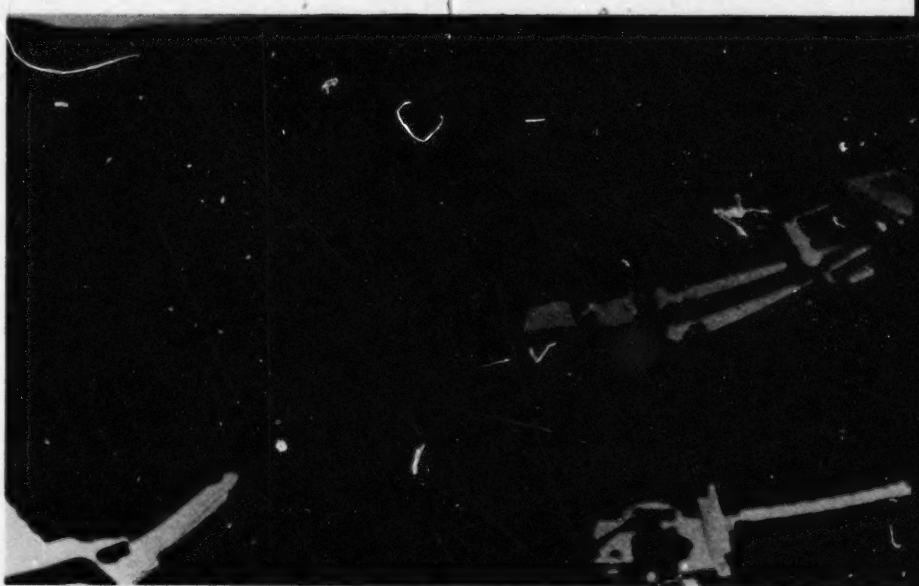


Figure 6. Early Morning on a Martian Desert. *The variety of the Martian surface is captured in this panorama by the Viking 1 Lander. The view covers a horizontal angle of about 100 degrees, about one-quarter of a circle. Martian northeast is at the left, southeast at the right. The newly-risen Sun is just above the center of the picture. Shapes of the small sand dunes (center and left) indicate that the winds that formed them blew from upper left toward lower right. Large boulder (left), named "Big Joe," measures 1 by 3 meters (3 by 10 feet) and is only 8 meters (25 feet) from the Lander. The vertical white object (center) is the Viking boom that holds the weather-measuring instruments.*

Figure 7. "Caution! Viking at Work!" *More than 300 million kilometers (200 million miles) from Earth, an historic and exciting excavating job produced this tiny trench in the surface of Mars. The trench, scooped out by the sample collecting arm of the Viking 1 Lander, is about 8 centimeters (3 inches) wide. The shape of the trench indicates that the Martian soil is fine-grained and about as cohesive as wet beach sand on Earth. The steep uncollapsed walls at the far end of the trench and the clods of soil piled up at the near end show how well the Martian soil sticks together.*

grayish bedrock. At other places, streaks of dust have been deposited over and behind boulders. When Viking 1 first landed, some of these piles of red dust were being eroded and blown away by the summer breezes that swirled around the Lander.

Sometimes the Viking cameras turned away from the landscape to study in detail the mechanical properties of the ground on which the Lander rests. The cameras carefully photographed the streaks produced in the soil by the rocket engines when Viking landed. Later, as the soil was trenched and probed and shaken to collect samples, the cameras recorded the appearance of marks, trenches, and clods of soil on the surface (Figure 7). By studying these pictures, scientists back on Earth were able to determine that the Martian soil is about as firm as good farming soil on Earth. The soil of Mars sticks together in about the same way, too; smaller particles clump together into larger clods, and the walls of shallow trenches remain straight and show little tendency to collapse.

Seen from the surface, the two Viking landing sites have their differences. The Plains of Utopia, where Viking 2 landed, are more rolling than the Plains of Chryse where Viking 1 sits. The Viking 1 site (Chryse) apparently has a larger variety of rock types, while the rocks at the Viking 2 locality (Utopia) are more uniform, generally vesicular (bubble-rich), and more abundant. There is bedrock exposed at the Chryse site, and none visible at Utopia.

There are rippled sand dunes at the Chryse location, and none at Utopia. The boulders at the Chryse site commonly have flat, polished faces, apparently produced by wind-blown sand.

The Utopia site (Viking 2) shows an unexplained pattern of shallow troughs that connect to form polygonal patterns. One of these troughs runs right past the Viking 2 Lander (Figure 8).

The Winds of Mars

For the first time we can now measure and record the weather on another world. Unlike the airless Moon, Mars has an atmosphere, winds, and weather patterns.

Mars' atmosphere is thinner and colder than Earth's, and scientists were eager to study its weather patterns in the hope of finding general principles that would help us better understand the weather of our own planet. The Viking cameras often looked above the horizon to photograph the sky, and a battery of instruments recorded winds, barometric pressure, and the chemical composition of the atmosphere of Mars (Figure 9).

Viking's first view of the sky produced a major surprise. Although many scientists had expected that the Martian sky would be blue like that of Earth, the Viking pictures showed instead that it has a creamy-pinkish hue (Figure 10). The explanation is that the Martian atmosphere contains a great deal of fine suspended red dust.

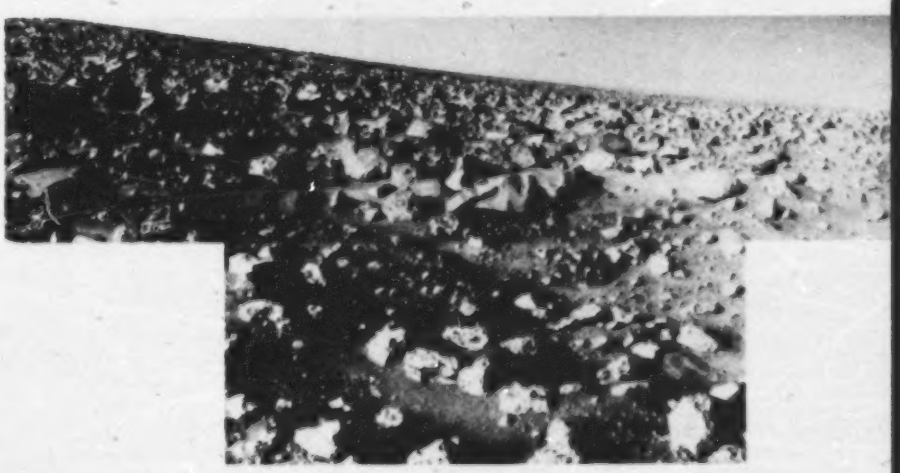


Figure 8. A Crowd of Martian Rocks. *Like a throng of curious onlookers, thousands of rocks and boulders surround the Viking 2 Lander as it rests on Mars' Plains of Utopia. The field of rock and soil extends to the horizon about 3 kilometers (2 miles) away. (The horizon, actually level, appears tilted because the spacecraft is resting on the surface at a slight angle to the horizontal.) Many of the rocks display small pits and holes that may be bubbles formed when the rocks were molten lava. The rock in the lower right corner is about 25 centimeters (10 inches) across, and the large rock in the center is about 60 centimeters (2 feet) long. The small sandy trough that winds across the picture from upper left to lower right is part of an unexplained network of such channels or depressions that form strange polygonal surface patterns in the Utopia region.*

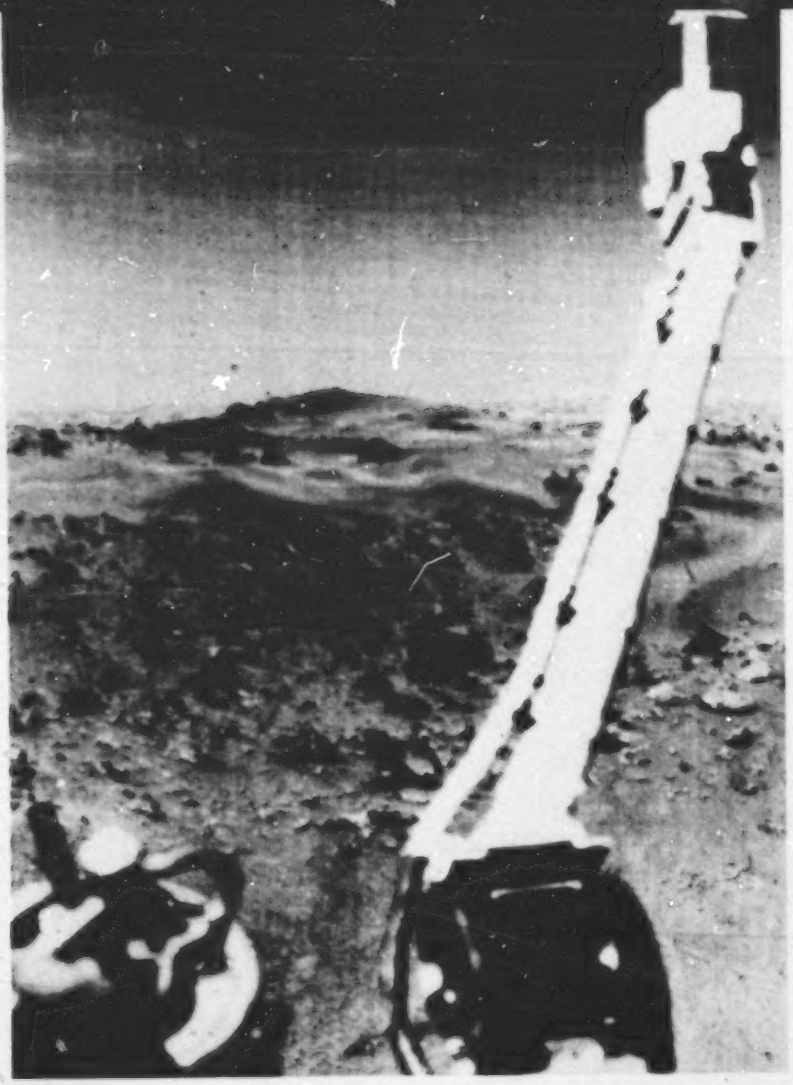


Figure 9. " And Now, the Weather for Mars." *The first interplanetary weather reports come from a small white instrument box (upper right) mounted on the end of a long boom that holds the box about 1.3 meters (4 feet) above the Martian surface. The boom holds the box out of range of most wind disturbances caused by the body of the Viking Lander. Instruments in the box measure the wind velocity, wind direction, temperature, and atmospheric pressure. In the background are sand dunes formed by strong Martian winds. The parallel bands in the sky are not real; they were produced by the computer processing of the picture.*

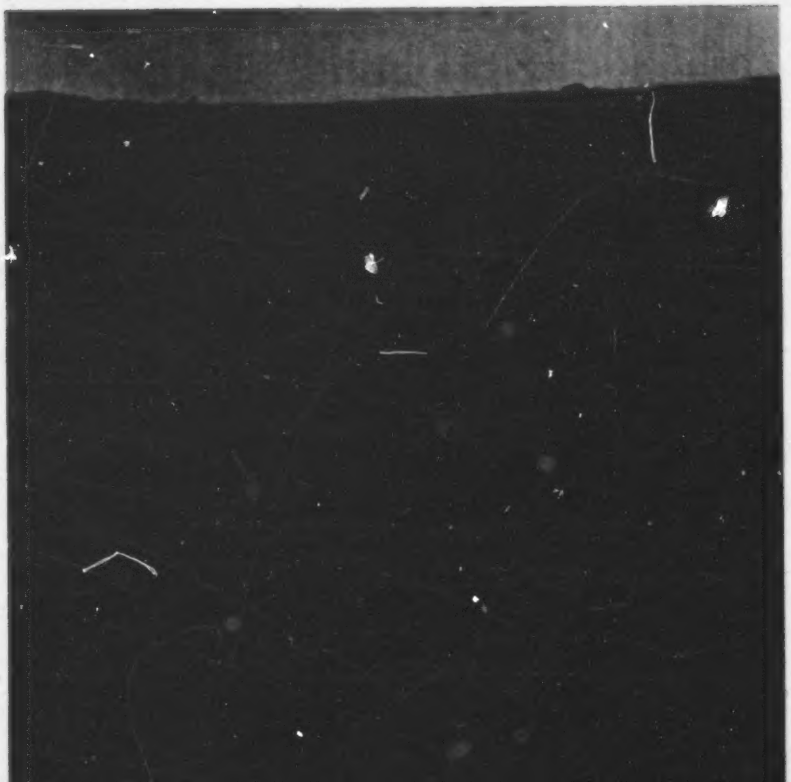


Figure 10. A Red Sky for a Red Planet. *The red surface of Mars lends its color to the Martian sky in this view from the Viking 1 Lander. Fine red dust from the soil is carried into the atmosphere, giving the sky a pinkish hue instead of the blue color expected by scientists. Light and dark boulders are strewn on the surface in the foreground, and light-gray ledges of bedrock appear through the soil in the middle distance. The horizon, about 100 meters (330 feet) away, may be the rim of an impact crater. This color picture was made by combining three separate pictures, each taken through a different color filter. The colors were matched by comparing similar pictures taken of colored objects on the Viking Lander itself.*

Although the individual dust particles are tiny, perhaps only 0.001 millimeter (1/25,000 inch) across, there is apparently enough of this dust in the air to give the whole sky a reddish tint. Earth's sky is generally not so dusty. Only after large volcanic eruptions or sandstorms do we see a reddening of terrestrial sunsets that produces something like the color of the Martian sky.

The sky of Mars grew even dustier several months after the Vikings landed, and the spacecraft carefully recorded the change.

Astronomers have known for years that huge dust storms often come swirling out of the southern part of Mars, covering the whole planet and shutting off the surface from the view of Earth-based telescopes. Such a storm shrouded Mars in 1971 as Mariner 9 arrived in orbit, and the spacecraft was able to provide a photographic record of the storm's subsidence and the gradual appearance of the Martian surface through the clouds of dust. These dust storms usually develop as Mars reaches the point in its orbit that is closest to the Sun, and in the Spring of 1977, these clouds arose again and spread over the Martian surface. High above the storms, the Viking Orbiter cameras photographed the shapes of the dust clouds and followed their progress. With these data, scientists are learning more about Martian winds and about the nature of the dust that they carry.

After Viking landed, the Martian weather was clear, cold, uniform, and repetitious. The weather report, recorded by the Viking instruments and broadcast to Earth on the first day, remained almost unchanged from day to day:

"Light winds from the East in the late afternoon, changing to light winds from the Southeast after midnight. Maximum winds were 15 miles per hour. Temperature ranged from minus 122° Fahrenheit just after dawn to minus 22° Fahrenheit in midafternoon. Atmospheric pressure 7.70 millibars."

(On Earth the same day, July 21, 1976, the lowest temperature recorded was minus 100 degrees Fahrenheit at the Soviet Vostok Research Station in the Antarctic, and the highest temperature was plus 117° F at Timimoun, Algeria. The United States recorded a high of 109° F. at Needles, California and a low of 37° F. at Point Barrow, Alaska.)

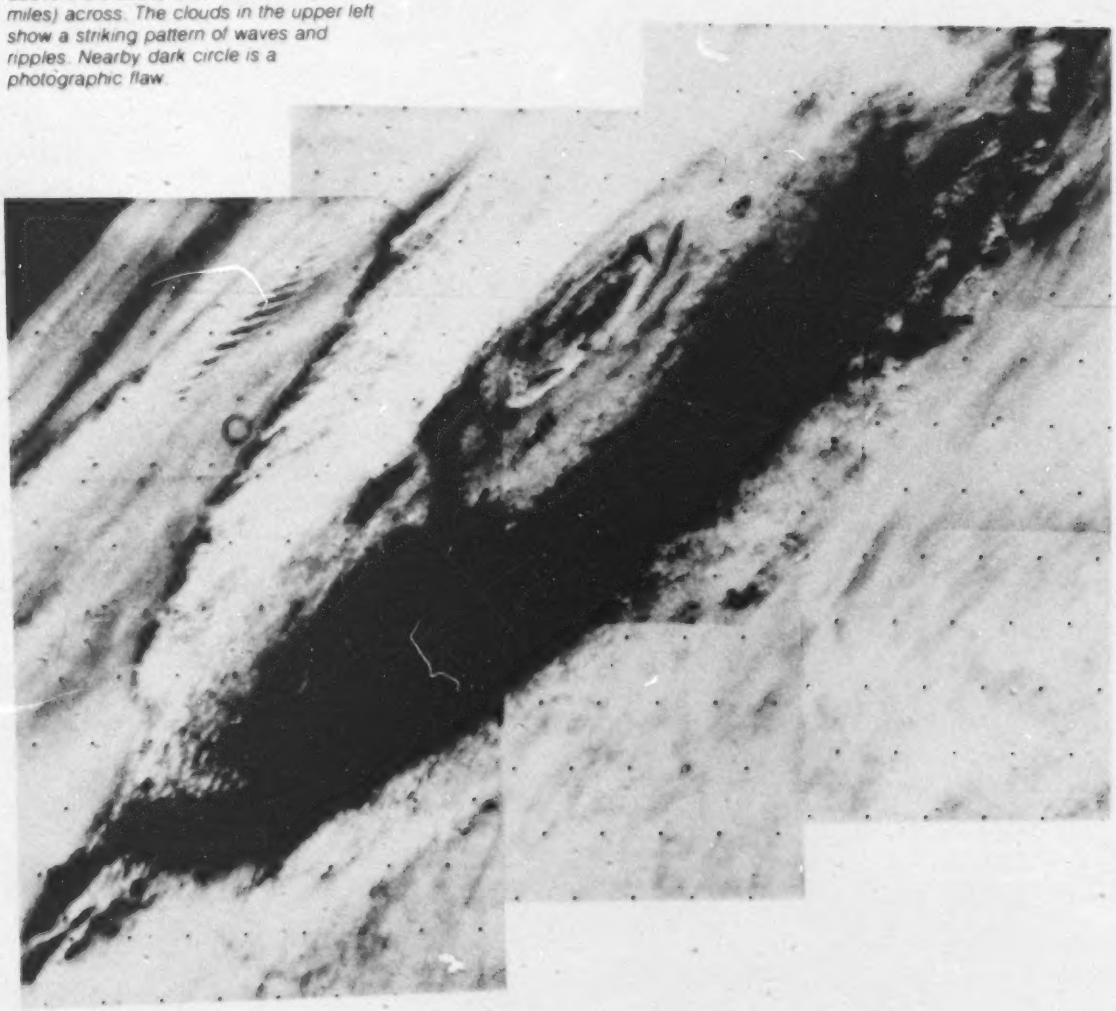
Some of the similarities between Mars' weather and Earth's were surprising, because the atmosphere of Mars is less than a hundredth as dense as Earth's. Nevertheless, on both planets, the atmospheric temperature reached its peak at about 3 P.M. local time. The daily temperature variations recorded by Viking showed the same pattern as records from a terrestrial desert "control" site at China Lake, California, although the temperatures in the two places differed by more than 83° C. (150° F.). Furthermore, the changing patterns of wind direction over the flat Plains of Chryse on Mars were duplicated by the winds blowing over the equally flat Great Plains of the midwestern United States.

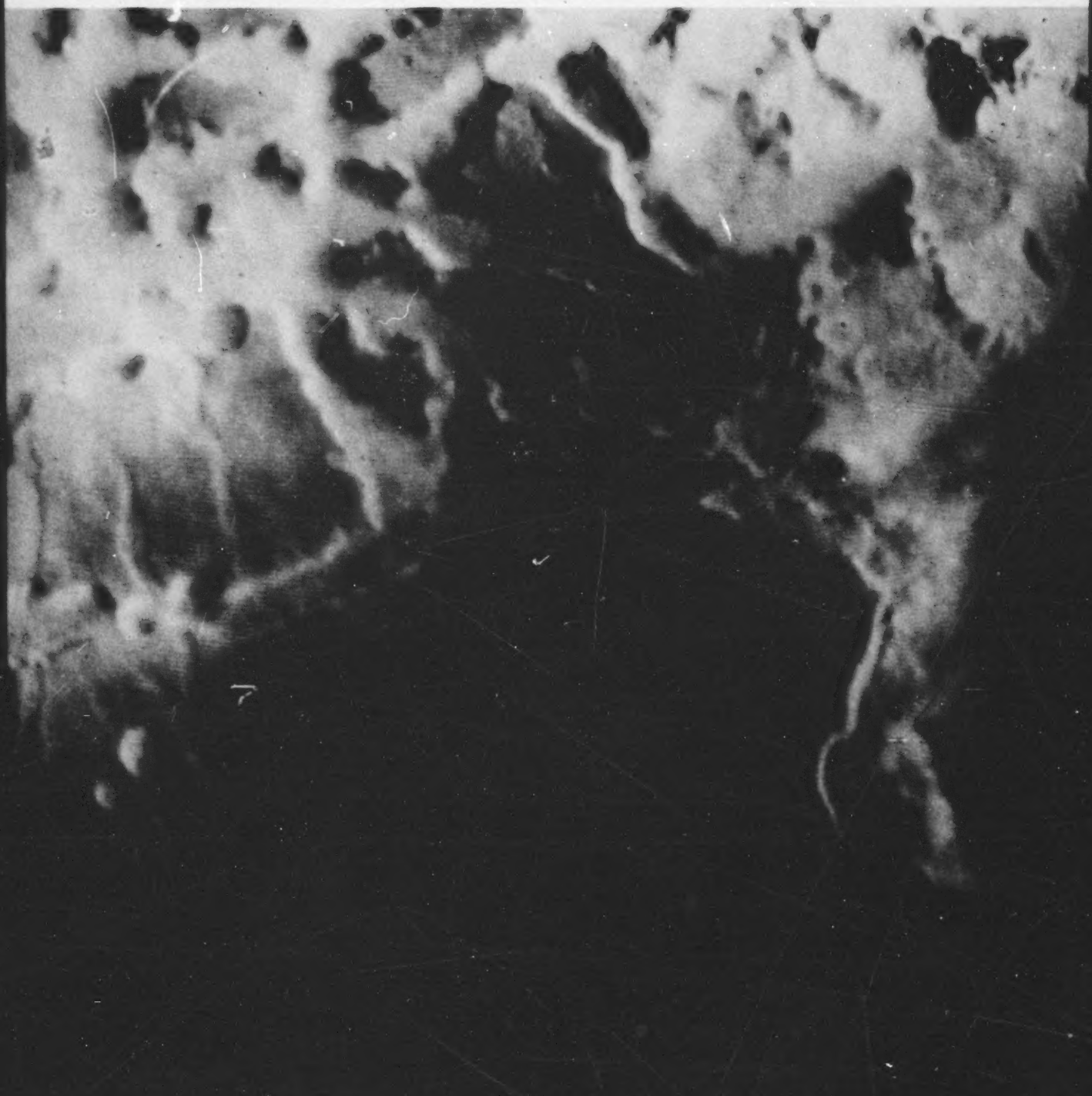
Martian weather includes two other features familiar to terrestrial weather watchers—clouds and fog. The air of Mars contains only about 1/1000 as much water as Earth's atmosphere, but even this small amount can condense out, forming clouds that ride high in the atmosphere or swirl around the high slopes of Martian volcanoes (Figure 11). In small valleys, atmospheric water freezes out during the Martian night and then vaporizes again when the sun rises, forming local patches of white fog that vanish quickly in the relative warmth of the Martian day (Figure 12).

Totally unlike the Earth, however, was the steady decline in atmospheric pressure recorded by the Viking instruments. During the Lander's first month on Mars, the atmospheric pressure dropped by about 5 percent. (On Earth, such a large drop in pressure is usually found only in the eye of a major hurricane.) Scientists think that the carbon dioxide (CO_2) which makes up most of Mars' atmosphere was freezing out as solid CO_2 (or "dry ice") on the cold southern polar cap, which was then in the middle of the Martian winter. The Viking landers thus seem able, from two points on the surface, to detect the slow growth of an entire polar cap thousands of kilometers away, a feat that would be impossible in the complex water-rich atmosphere of Earth.

While one group of scientists followed the changes in Mars' weather, an entirely different group was busy analyzing the chemical composition of the atmosphere itself. The gases in a planet's atmosphere can come from many different sources. Some gases may have been trapped from the original solar nebula when the planet formed. Others may have been released by heat and chemical

Figure 11. Martian Volcano Towers Above the Clouds. *In this Viking 1 Orbiter photograph taken from 8,000 kilometers (5,000 miles) away, clouds cover the lower slopes of Mars' largest volcano, Olympus Mons (Mount Olympus), making it look like a satellite picture of a terrestrial hurricane. The huge mass of the volcano is 600 kilometers (375 miles) across, and the cliffs that mark its edge can be seen in the upper right corner. The summit stands 24 kilometers (15 miles) above the Martian surface, and the summit crater, visible above the clouds, is 80 kilometers (50 miles) across. The clouds in the upper left show a striking pattern of waves and ripples. Nearby dark circle is a photographic flaw.*





reactions deep inside the planet. Still others may be produced by the transformation (decay) of radioactive elements in the planet's rocks. The chemistry of an atmosphere thus provides unique information about a planet's origin, its history, and the chemical composition of its rocks.

Earth's atmosphere is composed almost entirely of two gases: nitrogen and oxygen. Scientists believe that the nitrogen (78 percent of our atmosphere) came out of the interior of the Earth billions of years ago, while the oxygen (21 percent) has been produced gradually by the plant life that has existed for billions of years. A small amount of the inert gas argon (0.9 percent) has been formed by the decay of radioactive potassium atoms in the Earth's crust.

The composition of the Martian atmosphere was measured in two places—at high altitudes as the Lander descended, and on the surface. The composition was the same in both places, showing that the Martian winds keep the atmosphere as well-mixed as Earth's.

The pressure of Mars' atmosphere is only about 1/125 that of Earth's and its chemical composition is totally different. Most of Mars' atmosphere (95 percent) is carbon dioxide, a gas which makes up only 0.03 percent of Earth's atmosphere. The remainder is nitrogen (2–3 percent) oxygen (0.1–0.4 percent), and argon (1–2 percent). The discovery of nitrogen was exciting because this element is an essential component of the protein molecules which form living things. The small amount of free oxygen is surprising, but this element can be formed in many ways, and its presence does not prove that there is or has been plant life on Mars.

More precise analyses have detected traces of the rare inert gases krypton and xenon in the Martian air. These two gases make up only about 1 part per million of the Earth's atmosphere, and scientists have not yet been able to measure precisely the tiny amounts present in the air of Mars.

Viking instruments also measured the ratios of different isotopes in the Martian atmosphere. (Isotopes are two atoms of the same chemical element that have different atomic weights, for example uranium-235 and uranium-238.) Isotope ratios of elements in the atmospheres and rocks of other planets are important because they provide information that cannot be obtained from chemical analyses alone. Isotope measurements can indicate the temperature at which rocks formed; if two different planets have similar isotope ratios, then they may have formed from the same part of the original solar nebula.

The isotope ratios measured by the Viking Lander show that the atmosphere of Mars is more Earthlike than the chemical composition alone would suggest. The ratio of heavy to light carbon atoms (carbon-13 to carbon-12) is 1/89; and the ratio of heavy to light oxygen atoms (oxygen-18 to oxygen-16) is 1/500. These values are identical to those measured in our own atmosphere. However, the element nitrogen is different. The ratio of heavy to light nitrogen (nitrogen-15 to nitrogen-14) is 1/156 on Mars, while the value on Earth is 1/271.

The carbon and oxygen ratios demonstrate a basic similarity between Mars and Earth, despite the chemical differences in their atmospheres. One explanation is that both Mars and Earth formed from similar parts of the solar nebula which had the same isotope ratios.

However, the isotope ratios of nitrogen provide evidence for different histories of this element on the two planets. If the original nitrogen ratio on Mars had been the same as on the Earth, then the light atom (nitrogen-14) must have gradually escaped from the atmosphere of Mars, possibly because Mars' gravity is not as strong as Earth's.

From these atmospheric data, scientists have calculated that the ancient atmosphere of Mars, before

Figure 12. Foggy Morning in a Martian Valley. *White patches of early-morning fog and mist fill a rugged network of Martian canyons and spill out onto the surrounding high, rust-colored plateau. The clouds are probably formed by water vapor that has frozen out of the air during the previous Martian night. In the sunlight, the water vaporizes again, becoming briefly visible as mist before being absorbed into the dry atmosphere. This part of Mars, called Labyrinthus Noctis (The Labyrinth of the Night) was photographed at dawn by the Viking 1 Orbiter; the view covers an area about 100 kilometers (62 miles) on a side. The color picture was made by superimposing three separate black-and-white images taken through color filters.*

the nitrogen was lost, might have been four or five times as dense as it is now. This early atmosphere also might have contained enough water to form a layer several meters deep over the whole surface of the planet. Here was another indication that the winding channels on Mars actually had been carved by water, although the atmospheric analyses could not tell us where this water had vanished.

The Chemistry of Mars

While the atmosphere of Mars was giving up its secrets, other scientists with other instruments began to test the solid matter of the planet, to see what could be deciphered from the rocks and windblown dust around the spacecraft.

On the eighth day of Viking 1's residence on Mars, a long arm reached out from the spacecraft, and a small scoop at the end of the arm began to dig a small trench in the loose soil about two meters away from where the Lander stood (Figure 7). Continually guided by a computer aboard the Lander, the arm carefully pushed the scoop through the trench and then retreated slowly back to the Lander, bringing with it the first sample of Martian soil ever to be analyzed. Within the Lander, the soil sample was sieved automatically, divided, and sent on its way for several different kinds of analysis.

One test of the soil did not require a chemical laboratory. Several magnets were mounted on the scoop, and another magnet had been placed on the outside of the Lander. These magnets trapped and held magnetic particles in the soil and windblown dust. By simply examining these magnets with the Viking cameras now and then, the amount of magnetic material in the Martian soil could be measured. Early results suggest that about 5 per cent of the soil is magnetic material and that it is an iron oxide like magnetite (Fe_3O_4), the mineral that forms terrestrial lodestones. This result makes Mars seem rather Earthlike, the lunar soil, by contrast, has only about 1 per cent of magnetic material, and it is all metallic iron.

More precise measurements of the soil were made with an instrument that bombarded a soil sample with X-rays and then measured the secondary X-rays given off by the atoms in the Martian soil.

The composition of the Martian soil, as determined by the bombardment experiment, is approximately the same at both landing sites, even though the two sites are about 5000 kilometers (3100 miles) apart.

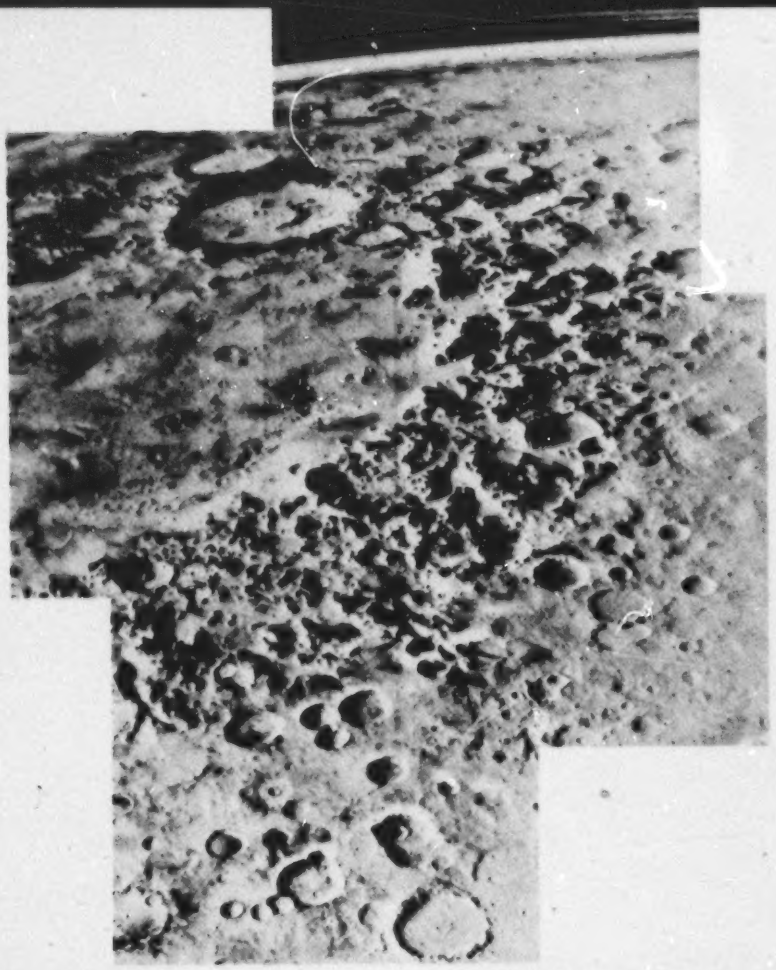
The chemical elements detected, and their amounts (in weight percent), are: silicon (Si) 21, iron (Fe) 13, aluminum (Al) 3, magnesium (Mg) 5, calcium (Ca) 4, sulfur (S) 3, chlorine (Cl) 0.7, titanium (Ti) 0.5, and potassium (K) less than 0.25. Scientists calculate that, to balance these elements, oxygen (O) makes up another 42 per cent of the soil, leaving about 8 percent made up of elements (e.g., sodium, hydrogen) that cannot be detected by this method.

This composition corresponds approximately to that of a terrestrial or lunar basalt lava, but there are some striking differences. The Martian soil contains less aluminum than a terrestrial basalt and less titanium than a lunar basalt.

The unusually large amount of iron detected confirms the long-held theory that the red dust of Mars is a red iron oxide similar to terrestrial rust. The red color and the small amount (about 5 per cent) of magnetic material suggest

Figure 13. The Ancient Crust of Mars. *Mars shows a battered and heavily-cratered Moon-like surface in this picture taken from the Viking 1 Orbiter from 18,000 kilometers (11,200 miles) away. The flat circular plain at top left is Argyre, a large impact basin about 800 kilometers (500 miles) in diameter and located in the southern part of Mars. This basin, surrounded by a rugged range of mountains, may have been formed by a huge meteorite impact billions of years ago. Smaller, younger craters cover the Martian surface outside the basin. The air is clear and cloudless over Argyre, but the brightness of the distant Martian horizon (top right) suggests that clouds are present there. The parallel white streaks above the horizon are also cloud layers, perhaps composed of frozen CO_2; these clouds are about 25 to 30 kilometers (15 to 20 miles) above the surface of Mars.*

Figure 14. A View Down a Volcano's Throat. *From 6,000 kilometers (3,700 miles) up, the cameras of the Viking 1 Orbiter provide a vertical view of Arsia Mons, one of Mars' largest volcanoes. The volcano reaches about 19 kilometers (12 miles) above the surrounding Martian terrain, more than twice as high as Earth's Mount Everest. The circular central area in its summit is about 120 kilometers (75 miles) across. Around this summit crater, the slopes of the volcano are covered with lava flows that produce distinctive braided patterns seen clearly at the bottom of the picture. At left and right, small craters and canyons cut into the main cone of the volcano; these features may be the sources of vast amounts of lava that spilled out to flood the surrounding plains.*



that the iron must be present in two or more distinct minerals, only one of which is magnetic.

The chemical analyses indicate that the Martian soil cannot be made of fresh basalt lava alone. The presence of water (perhaps as much as 1 per cent) in the soil, the large amount of iron, and the unusually large amount of sulfur, all indicate that the soil is a mixture of original basalt lava with other compounds that have formed as the rock has been changed or "weathered" by contact with the atmosphere of Mars. The soil could be a mixture of iron-rich clay minerals and other compounds such as iron hydroxide and magnesium sulfate.

The soil of Mars is much more similar to Earth's soil than to the soil of the Moon. The lunar soil, as we have learned from the samples returned by the Apollo missions, is waterless, unweathered, and formed by the continuous bombardment of large and small meteorites. Martian soil seems almost terrestrial: it contains water, it seems to be weathered, and it is continually blown about and redistributed by the wind.

Three Chances for Life

A major goal of the Viking missions was to determine whether the soil of Mars was dead like the soil of the Moon or teeming with microscopic life like the soils of Earth. Soil samples brought into the Lander were divided and sent to three separate biological laboratories to be tested in different ways for the presence of life.

Searching for life on Mars raises a basic problem, best summed up as: "How do you look for life if you don't know what life looks like?" It was not possible to build, on one small spacecraft, enough instruments to detect all the possible forms of life that scientists could imagine to exist on Mars. Before building the instruments, the scientists had to make some decisions about what the instruments should look for.

The Viking experiments were designed around two assumptions. First, it was assumed that Martian life would be like Earth life, which is based on the element carbon and thrives by transforming carbon compounds. Second, the example of Earth shows that where there are large life forms (like human beings and elephants), there are also small ones (like bacteria), and that the small ones are far more abundant, with thousands or millions of them in every gram of soil. To have the best possible chance of detecting life, an instrument should look for the most abundant kind of life. If a Martian version of Viking were sent to Earth to look for life, it might easily land in a place where there were neither elephants nor humans, but it would be very unlikely to land in a place where there were no bacteria in the soil.

The Viking instruments were designed, therefore, to detect carbon-based Martian microbes or similar creatures living in the soil. The three laboratories in each Lander were essentially incubators, designed to warm and nourish any life, living or dormant, in the Martian soil and to detect with sensitive instruments the chemical products of the organisms' activity.

One characteristic of terrestrial organisms such as plants is that they transform carbon dioxide (CO_2) in the surrounding air into the organic compounds which make up their roots, branches, and leaves. Accordingly, one Viking biological experiment, designated *carbon assimilation* (or pyrolytic release) added radioactive CO_2 to the confined atmosphere above the soil sample. The sample was then illuminated with simulated Martian sunlight. If any Martian life-forms converted the CO_2 into organic compounds, the compounds could be detected by their radioactivity.

Living terrestrial organisms give off gases. Plants give off oxygen, animals give off carbon dioxide, and both exhale water. A second experiment on each Lander, the *gas exchange* experiment was designed to detect this kind of activity. Nutrients and water were added to the soil, and the chemical composition of the gas above the soil was continuously analyzed for changes that might indicate biological activity.

A third experiment on each Lander was based on the fact that terrestrial animals (including humans) consume organic compounds and give off carbon dioxide. The *labeled release* experiment added a variety of radioactive nutrients to the soil, then waited to see if any radioactive CO_2 (derived from consumption of this "food") would be given off.

Several soil samples were processed by all three instruments on each Lander. The results? Puzzling. There is definitely some form of activity in the Martian soil, but it is not yet clear whether this activity is caused by Martian life or by some unusual chemical characteristic of the soil itself.

Viking has given us some chemical information about the Martian soil, but

Figure 15. Landslides Fill Martian "Grand Canyon". *This Viking 1 Orbiter picture, taken from a range of 2,000 kilometers (1,240 miles) shows a small segment of the Valles Marineris ("Mariner Valley"), a huge gash that runs east-west for almost 5,000 kilometers (3,000 miles) along the equatorial region of Mars. This part of the canyon is more than 50 kilometers (30 miles) across and 2 kilometers (1.3 miles) deep. The aprons of debris on the canyon floor show how the canyon widens as its walls collapse and produce immense landslides. The large apron in the center has overridden and partly covered an older landslide deposit to the left. The lines in the deposits indicate the direction in which the material flowed after breaking away from the canyon walls. White streaks in the middle of the canyon are features produced by winds blowing along the length of the canyon. Upper walls of the canyon provide a cross-sectional view through the different rock layers that cover this part of Mars: hard, resistant rocks (lava flows) at the top overlie less durable rubble (wind-blown dust or volcanic ash) below. Dark circle near center is photographic flaw.*

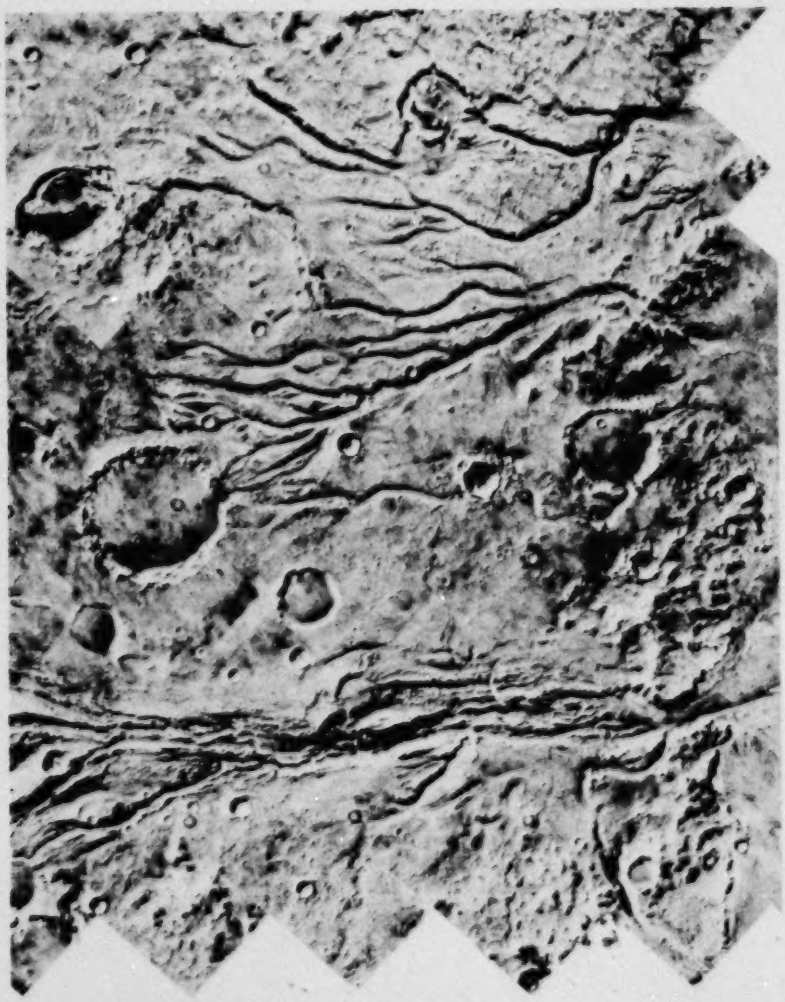


Figure 16. The Vanished Rivers of Mars. *Cameras in the Viking 1 Orbiter photographed this maze of wandering channels that cut across the terrain west of the Viking 1 landing site. The surface slopes downward, dropping about 3 kilometers (2 miles) in elevation from left to right. Flood waters once poured across this region from left to right, cutting through a high ridge (right) to pour out into the plains to the east. Older craters were cut, filled, and eroded by this flood. Younger craters, formed after the flood, show sharp outlines. The fate of these torrents is unknown: the water may now be frozen as ice in the polar caps or as permafrost in the Martian soil. Rows of dark circles are photographic flaws.*

we still do not know enough about its nature to predict what reactions will occur when water and nutrients are added to it in Viking's biological laboratories. The Martian soil may contain many unusual and unexpected chemicals, possibly formed by the repeated blasts of ultraviolet radiation from the Sun that penetrate the thin atmosphere of Mars and blanket the surface of the planet. Earth's soils are not affected in this way, because the Sun's ultraviolet light is absorbed by our denser atmosphere, and the chemistry of Martian soil could very well be unpredictably different from the soils of our own planet. Even if Martian soil is completely lifeless, it is possible that some reactions with the added water and nutrients are imitating biological activity.

Because of these uncertainties, scientists are being cautious in their interpretations of the biological experiments, even though many of the results resemble those from tests made on terrestrial soils rich in living organisms.

The *carbon assimilation* experiment showed that a small amount of CO_2 had been converted into carbon compounds, but this conversion could have been accomplished by some reducing agent in the soil, such as metallic iron.

In the *gas exchange* experiment both oxygen and CO_2 were given off when water was added to the soil. However, these reactions could have been caused by the decomposition of oxygen- and carbon-rich materials that originally had been produced in the soil by ultra-violet light.

Finally, the *labeled release* experiment showed a rapid release of radioactive CO_2 that at first seemed to be caused by biological activity. But the release quickly slowed down, suggesting that some chemical in the soil was being rapidly used up, whereas a biological reaction should have continued as the organisms grew and multiplied.

One problem with a biological interpretation of these reactions is that analyses of Martian soil by another Viking instrument have detected none of the organic carbon molecules that make up living things. It is hard to understand how these chemical reactions could be caused by Earthlike microbes that leave no other trace, living or dead, in the Martian soil.

At the moment, we know that there are reactive ingredients in the soil of Mars, but it will take more experiments and more examination of the Viking data before we know just what they are. As this work goes on, the separate Viking experiments support and reinforce each other, each one providing data to help interpret the results of another. The chemical analyses of the soil, made by X-ray methods, are used to help interpret the puzzling results of the biological experiments. The instrument that has looked in vain for organic carbon molecules has also measured the amount of such inorganic gases as water and sulfur dioxide in the soil. When these data are combined and evaluated, we may have some more definite answers about the chemicals, the minerals, and, perhaps, any life forms in the red soil of Mars.

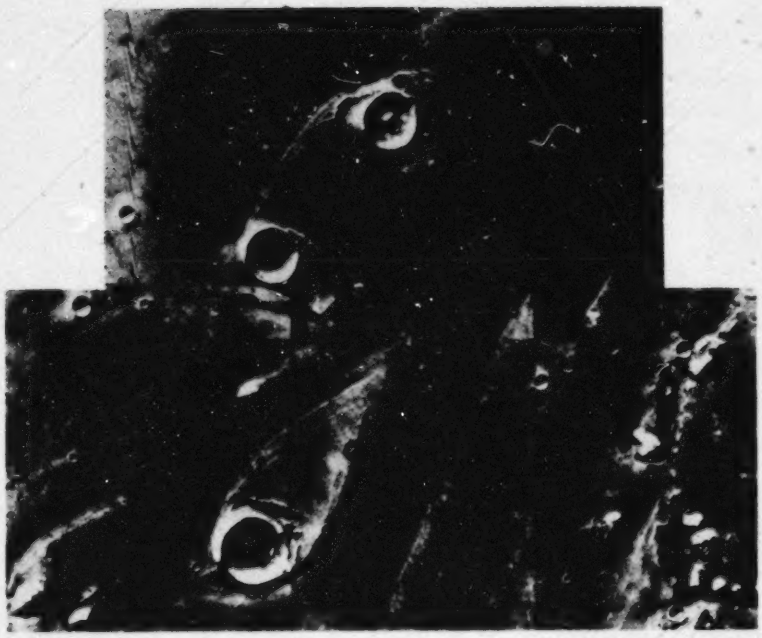
From Mars to Einstein

Late in November, 1976, Mars passed behind the Sun, and communications between Earth and Viking were cut off until mid-December, when Mars appeared on the other side of the Sun. As Mars passed behind the Sun, the Viking spacecraft carried out a major experiment to study, not Mars, but the basic nature of the universe itself.

The spacecraft signals from Mars made it possible for scientists on Earth to carry out the most accurate test ever performed of Einstein's Theory of

Figure 17. Islands in the Stream *The raised rims of these Martian craters seem to have acted as barriers to floods of water that poured across the surface of Mars in the past. The upstream (lower left) sides of all the craters seem eroded, with streamlined islands left on the downstream (upper right) side. A curiously shaped ejecta deposit still preserved around the uppermost crater may have been above the level of the floods. This spectacular scenery, photographed by the Viking 1 Orbiter from 1600 kilometers (1000 miles) above Mars, is located near the Viking 1 landing site on the Plains of Chryse. (Small dark rings in the picture were caused by a flaw in the camera.)*

Figure 18. The Source of the Flood? *This strange Martian valley, more than 50 kilometers across, shows a striking change from a chaotic, hilly floor at its head (right) to a narrower and more streamlined shape (left). One explanation is that water, frozen below the Martian surface, suddenly melted and ran out, causing the ground to collapse and producing a short-lived torrent that eroded the downstream part of the valley. Such "collapsed terrain" is common in this part of Mars; numerous large and small impact craters can also be seen. A smaller valley, possibly produced by a smaller flood, is visible near the large impact crater at the top of the picture. This picture was taken by the Viking 1 Orbiter from a distance of 2300 kilometers (1900 miles). (The small dark rings in the picture are caused by a flaw in the camera.)*



General Relativity. The theory, which explains gravitation and the relationships between space and time, predicts that light waves (or radio waves) will be slowed down as they pass close to a large and massive object like the Sun. Precise measurement of the delay in radio transmission from the Viking spacecraft as Mars went behind the Sun would test whether the General Relativity Theory was correct or whether some competing theory was a better explanation of how our universe works.

On the day of the experiment, November 25, 1976, Mars was about 321 million kilometers (200 million miles) from Earth, and the radio signals took about 42 minutes to make the round-trip. But the timing and signalling devices used in Viking communications are so accurate that the transmission time could be measured to one ten-millionth (0.0000001) of a second. With such accuracy, it was not difficult to determine that the radio signals from Mars had been delayed by a full two ten-thousandths (0.0002) of a second—exactly the delay predicted by the Theory of General Relativity.

This Viking relativity experiment was also the most accurate measurement of distance ever made: the 321-million-kilometer Earth-Mars distance was determined with an accuracy of about 1.5 meters (5 feet)!

What Next?

Although most of the Viking excitement was concentrated in the first few months after the landings, it is likely that the Viking Orbiters and Landers will operate for a year or two, sending back photographs and other information from Mars. Each Lander has a long-lived nuclear power source, and each Orbiter gets electricity from large solar cell arrays backed up by two nickel-cadmium batteries.

Scientists are eager to use the Lander instruments to follow the weather patterns at Chryse and Utopia through the Martian fall and winter, and into the spring when the time of planet-wide dust storms is thought to begin. A complete weather record of the Martian year, which is two Earth-years long, would be a unique document that could lead to better understanding the weather and climate on Earth and other worlds.

Geologists are also eager for a long period of Viking data. The Viking Landers carry seismometers to detect "Marsquakes" so that scientists can determine whether Mars is active like the Earth or dead and quiet like the Moon. Unfortunately, the instrument on Viking 1 did not operate.

Since Viking 2 landed in September, 1976, its sensitive seismometer has been steadily recording the tiny vibrations caused by the wind and the mechanical devices on the spacecraft.

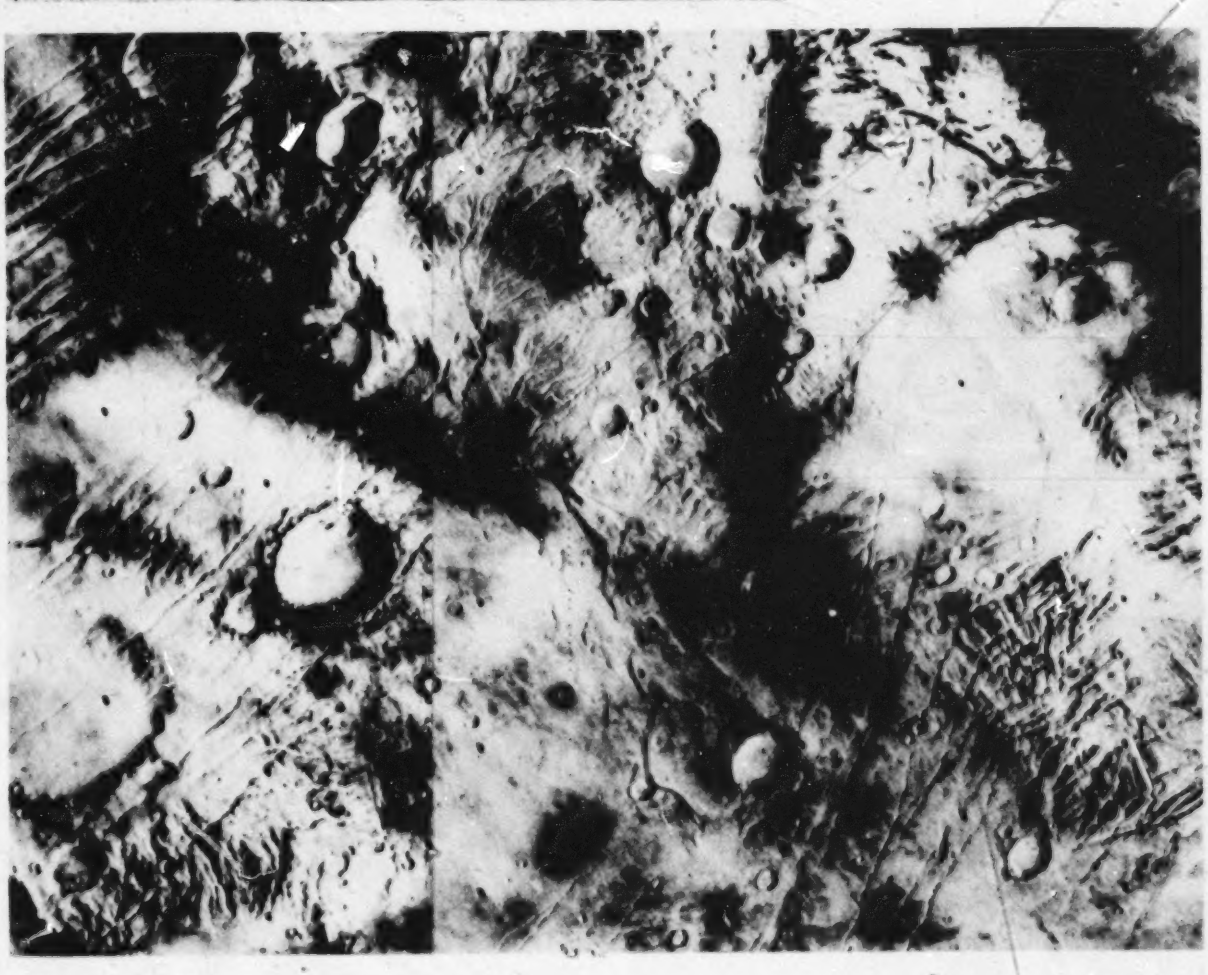
A distinctive "event" in early November, 1976, may have been a quake with a Richter magnitude of 6.4, fully as large as the major San Fernando earthquake that struck the Los Angeles area in 1971.

Overhead, the two Orbiters continue to take pictures of the surface of Mars and to measure the amount of water vapor in the Martian air and the temperatures of the Martian surface.

Even before the Landers touched down, the Orbiters had provided new high-resolution photographs of the major features of Mars: circular basins and mountains (Figure 13), huge volcanoes (Figure 14), great canyons and landslides (Figure 15), mazes of

Figure 19. Splat? *The crater Yuty, 18 kilometers (11 miles) in diameter, looks entirely different from the numerous craters that cover the Moon and Mercury. The high central peak inside this crater, and the scalloped blanket of ejected material around it, make Yuty look like a large-scale version of a crater formed by throwing a pebble into thick mud. One possible explanation for this resemblance is that large quantities of frozen water beneath the Martian surface were instantaneously melted by the heat produced by a large meteorite impact. As a result, huge "mud avalanches," made of water and broken rock, poured out of the crater to form the curiously-shaped blanket around it. This view was taken by the Viking 1 Orbiter from a range of 1877 kilometers (1165 miles). (Yuty is named for a village in Honduras.)*

Figure 20. Cracks in the Martian Crust? *This part of Mars, west of the Argyre Basin, is cut by numerous parallel fractures (faults) that run for hundreds of kilometers through circular craters and flat plains alike. The dominant set of fractures (top left) runs from lower left to upper right, but other fractures run in other directions (see lower right). The fractures may be the surface effects of slow movements in the interior of the planet. The small fan-shaped channels (top center) may have been cut by running water at some time in the past. The light-colored region (top right) is part of a frost deposit associated with Mars' south polar cap.*



winding, water-cut channels (Figures 16, 17, and 18), and craters with curiously scalloped deposits around them (Figure 19). Large areas of Mars are covered with strange patterns of fractures and joints in the bedrock (Figure 20), and with unexplained polygonal markings that resemble, on a large scale, the permafrost or "patterned ground" of Earth's Arctic regions.

On September 30, 1976, the orbit of the Viking 2 Orbiter was shifted so that the spacecraft could swing over the polar regions of Mars. This maneuver made it possible to study in detail the mysterious white polar caps that were one of the first features of Mars to be seen through Earth-based telescopes.

The Orbiter found that the amount of water in the atmosphere varies greatly. It is almost zero near the south (winter) polar cap, then increases dramatically as one moves northward into the northern (summer) hemisphere of Mars. Over the north polar cap itself, the atmospheric water content decreases and the instruments indicate that the surface temperatures are about −60° C. (−96° F.).

Cold as these temperatures are, they are above the freezing point of CO_2 in the Martian atmosphere, and scientists are now sure that the permanent polar caps on Mars are made of water ice instead of frozen CO_2 ("dry ice"). The polar caps thus contain a large reservoir of the water that may have cut the channels on Mars in an ancient and warmer time.

The cover of ice is not continuous, and the northern polar cap is cut by steep-sided ice free valleys (Figure 21). High-magnification pictures of the valley walls (Figure 22) revealed to surprised scientists that the "bedrock" beneath the polar ice is composed of layer upon layer of what may be windblown dust. Here under the polar cap may be preserved the records of the changing climates of Mars during thousands or millions of years in the past. Some individual layers, as much as 50 meters thick and covering hundreds of square kilometers, may have been deposited by huge sandstorms far more violent than any observed on Mars today.

When the Orbiters finish their task, much of Mars will be photographed, mapped, and studied in great detail, and future missions to Mars will be planned with better maps than many terrestrial explorers have had.

The Vikings also explored other worlds near Mars. In February, 1977, the Viking 1 Orbiter made two close approaches to Phobos, one of the two moons that circle Mars. From as close as 120 kilometers (75 miles) away, the Viking cameras photographed the irregular, cratered surface of Phobos in such detail that tiny craters and mounds a few meters across can be seen in the pictures (Figures 23 and 24). Many scientists think that Phobos, which is only 20 kilometers (12 miles) in diameter, is an asteroid that was captured by Mars at some time in the past. If they are right, the Viking cameras have given us our first close look at what we will find when we venture beyond Mars into the millions of tiny bodies that occupy the Asteroid Belt itself.

Even as the Viking data continue to flood in, there are active discussions

Figure 21. The Land of the (Martian) Midnight Sun. *The north polar region of Mars is displayed by the camera of the Viking 2 Orbiter as the spacecraft passed over the Martian Arctic for the first time in October, 1976. Broad regions of white ice are broken by darker slopes and valleys cut into layered rocks that underlie the icecap itself. Individual rock layers appear as curved parallel lines that follow the contours of the slopes and valleys. Measurements of the surface temperature, made by instruments carried on the Orbiter, indicate that the ice is frozen water, not frozen carbon dioxide. Top to bottom of the picture is about 360 kilometers (225 miles). The Martian north pole is about 300 kilometers (170 miles) beyond the top of the picture. (Just like the Earth's Arctic regions in summer, this part of Mars also has a "midnight sun"—or total daylight—because the inclination of Mars' axis and the length of the Martian day are almost identical to Earth's.*

Figure 22. A Valley that Cuts into the Past. *Walls of a deep valley, eroded in the Martian north polar cap, display the layered deposits of rock or windblown dust that underlie the polar ice itself. Individual layers as little as 50 meters (165 feet) thick can be detected, even though the picture was taken from about 2200 kilometers (1370 miles) away. The different layers may record many past changes in the Martian climate, by the same mechanisms that produce the changing ice ages on the Earth. Dark smudges on the ice surface may be recent deposits of windblown dust. This closeup view, taken in Martian mid-summer (October, 1976) by the Viking 2 Orbiter, shows an area of the polar cap about 60 by 30 kilometers (37 by 18 miles). Water ice (white) covers a high, level plateau, and the steep wall of the valley (top) drops about 500 meters (1650 feet) from the ice layer to the bottom. This color picture was made by combining black-and-white pictures taken through three different color filters.*

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about follow-up missions to Mars that can now be planned on the basis of what we have already learned. For all that Viking has done, it is only a beginning. what we have learned from the robots on Mars is still not much more than we had learned from the robots (Surveyor spacecraft) that we sent to the Moon before the first astronauts landed there. We know that the surface of Mars will support the weight of machines and humans. We have the first rough chemical analyses of the soil. We have taken pictures of the surface and dug trenches in it. And we can now make excellent maps of the planet and pick the sites for future landings.

To send astronauts to Mars would be a major undertaking. Not only would a manned mission require extensive technological developments, but there are serious medical problems involved in keeping the crew physically fit during a two-year trip in zero gravity.

For the near future at least, machines must do our exploring for us. One possibility would be a robot "rover" that would land on Mars and then drive across its surface, making chemical and biological analyses as it went. Another possible mission would involve a new kind of Orbiter around Mars, one that would carry instruments to measure the chemical composition of Mars' surface, just as instruments carried on the Apollo spacecraft mapped the chemistry of nearly one-quarter of the Moon. From this Orbiter, probes could be dropped to the surface, carrying instruments especially designed to survive the shock of a hard landing. In this way a network of instruments could be placed on Mars to give us global coverage of the planet's chemistry, Marsquakes, and weather.

More ambitious, but entirely within our abilities, is a more complex robot that would land on Mars, collect samples of rocks and soil, and return them to Earth, where they could be studied directly with the resources of all of Earth's laboratories. Only in this way can we make the thousand necessary analyses that are too complex to be made by machines on the surface of Mars. Only with such returned samples can we determine with confidence the ages of the rocks, the minerals that compose them, their complete chemical composition, and the weathering they have undergone. With instruments that are now available, we could finally establish beyond doubt whether such returned samples contain any Martian life. With the experience of a decade in space, and with the knowledge gained from sampling the Moon, we can collect, preserve, and analyze such samples from the surface of Mars whenever we choose.

The Vikings have become a bridge into the future. When the Landers have sent their last data back to Earth, they will remain like monuments on the surface of Mars, waiting silently until new machines, and finally human beings, come to stand beside them. (Figure 25.)

Figure 23. A Battered Moon of Mars. *Even tiny craters in the surface of Mars' innermost moon, Phobos, are captured in this photograph taken by the Viking 1 Orbiter cameras on February 18, 1977. To take this picture, the spacecraft came as close as 480 kilometers (300 miles) to the tiny moon, photographing features as small as 20 meters (65 feet) across. Phobos is elliptical in shape; the top-to-bottom diameter is 19 kilometers (12 miles), but diameters in other directions are 21 kilometers (13 miles) and 27 kilometers (17 miles). Because of its irregular shape and ancient, cratered surface, scientists think that Phobos may be an asteroid that was captured by Mars, possibly billions of years ago. A large crater at the lower right is named Hall after the American astronomer who discovered the two moons of Mars in 1877. The ragged appearance at the right side is produced by shadows on the unlit parts of Phobos' irregular surface.*

Figure 24. A Moon About to Break? *Parallel lines of fractures and craters extend across the whole surface of Mars' inner moon Phobos. Some scientists think that the whole moon is gradually breaking up from the impacts of large meteorites and from the tidal forces produced during its rotations around Mars. In the future, Phobos may disintegrate completely into small fragments, forming a ring around Mars like the familiar rings of Saturn or the similar rings discovered recently around the distant planet Uranus. This picture was taken by the Viking 1 Orbiter as it passed within 300 kilometers (200 miles) of Phobos on May 27, 1977. The picture on the right is the original data; the left-hand picture is the computer-processed version.*

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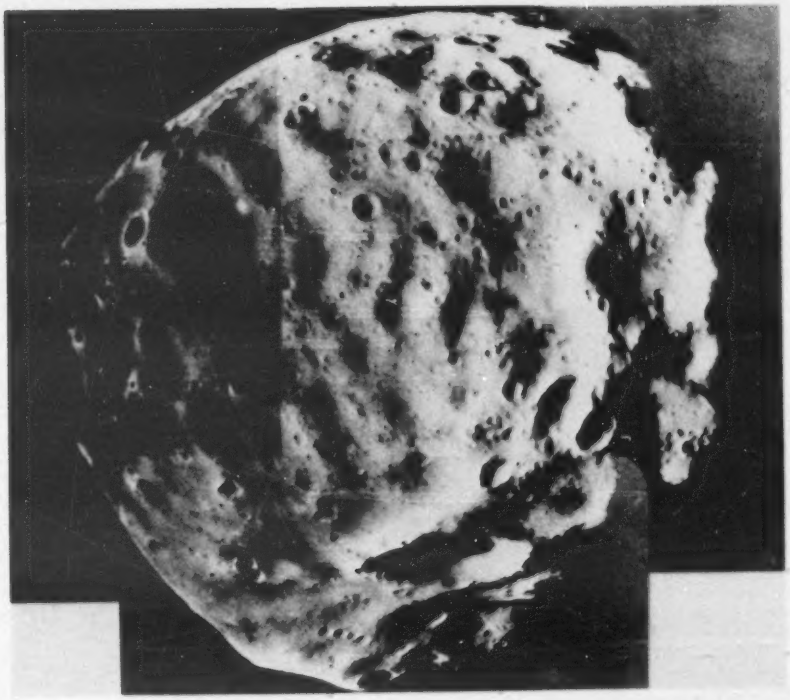

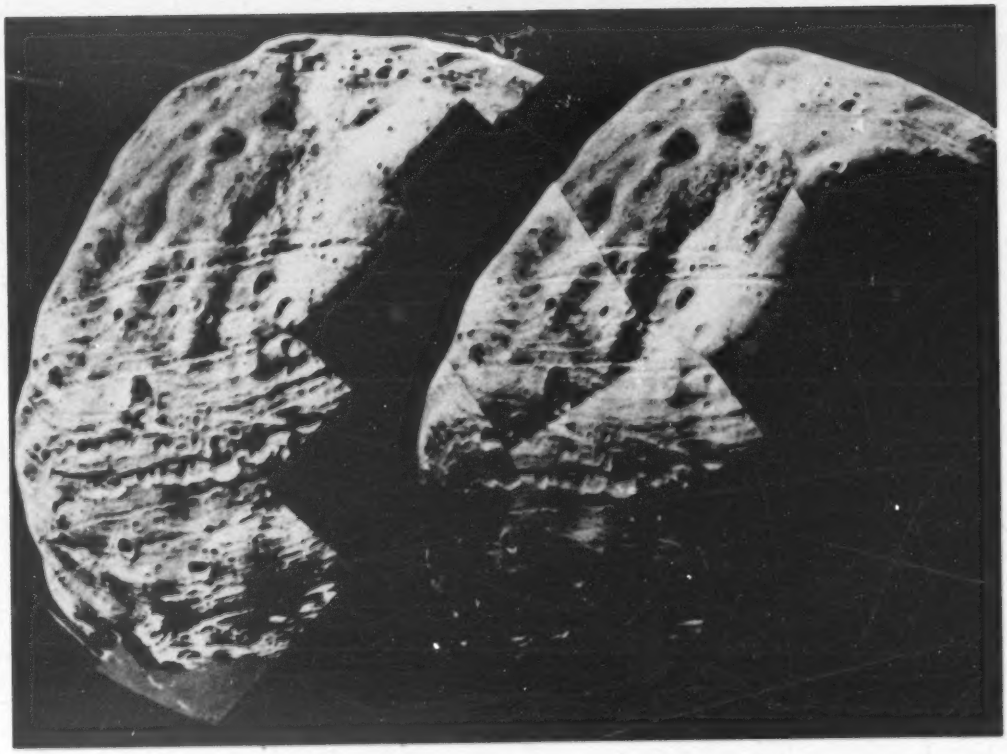

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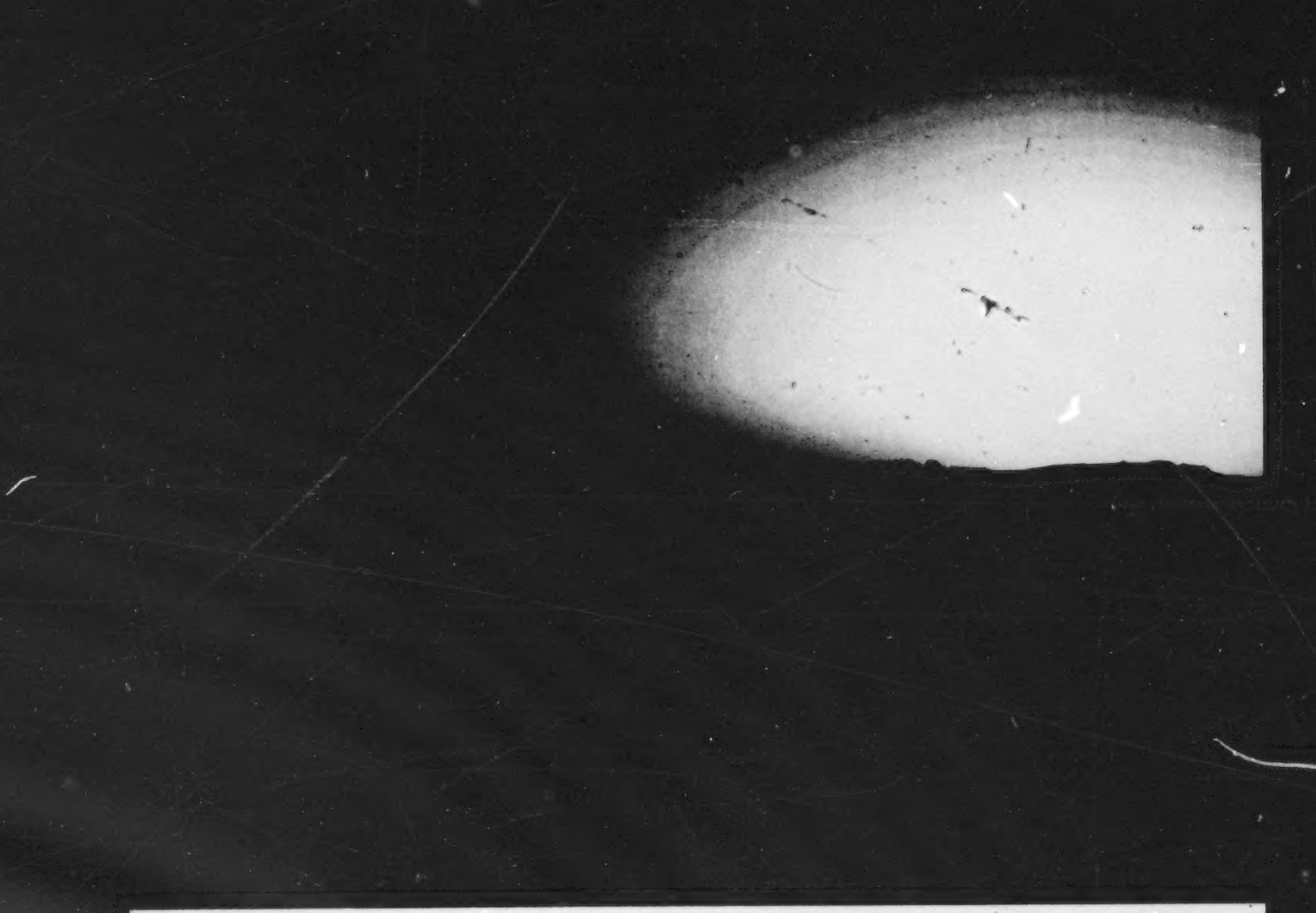

Figure 25. A Viking Sees a Sunset on a New World. *The Sun has set on Mars, but a lingering twilight brings a reddish glow to the Martian surface (left) and to the top of the Viking 1 Lander (lower right). The light of the Sun is scattered by red dust in the atmosphere, coloring the surface and producing a reddish color in the sky where the Sun has set. Near the Sun, the picture is overexposed, and that part of the sky appears white (upper right). The colored rings around the white spot are not real; they are produced during the computer processing of the camera's pictures. A human eye, looking at the same scene, would see a black night sky, grading uniformly into a reddish glow where the Sun has set.*

Figure 26. "Mars, this is Viking . . . Viking, this is Mars." *An apparent welcoming committee of lava-like Martian rocks is framed by the radio antenna (top) and other instruments on the Viking 2 Lander. The pink color of the sky is produced by fine red dust carried by the Martian winds. The American flag (left) and several color calibration charts helped scientists determine the actual color of the Martian sky and landscape from the pictures returned by Viking's cameras.*

Appendix

Suggestions for Further Reading

The Planet Mars

Avener, M.M., and R.D. MacElroy (1976), *On the Habitability of Mars*, NASA Special Publication SP-414, U.S. Government Printing Office, 105 p., price $5.25. A long-range consideration of whether life can survive on Mars and of how we might bring life . . . including ourselves . . . to the planet to change its present environment into something more Earthlike.

Bradbury, R., A.C. Clarke, B. Murray, C. Sagan, and W. Sullivan (1973), *Mars and the Mind of Man*, New York, Harper and Row, 143 p., price $7.95. A collection of essays about Mars, in which five scientists and writers discuss their feelings about Mars and what might be found there as Mariner 9 went into orbit around the planet in 1971. The book also presents some later reactions of the same people to the discoveries made by the spacecraft.

Carr, M. (1976), "The Volcanoes of Mars," *Scientific American*, Vol. 234, No. 1, January, 1976, pp. 32–43. A detailed discussion of the huge volcanoes discovered on Mars in 1971 by the Mariner 9 spacecraft: their size and appearance, their differences from terrestrial volcanoes, their ages, and what they tell about the history and internal structure of Mars.

Glasstone, S. (1968), *The Book of Mars*, NASA Special Publication SP-179, U.S. Government Printing Office, 315 p., price $5.25. A thorough compilation, now somewhat dated, of our knowledge about Mars in the pre-Mariner and pre-Viking years. Still a useful source of information about the general characteristics of Mars and the history of study of the planet.

Hartmann, W.H., and O. Raper (1974), *The New Mars: the Discoveries of Mariner 9*, NASA Special Publication SP-337, U.S. Government Printing Office, 179 p., price $8.75. A beautifully illustrated textbook that combines the early discoveries about Mars with the findings of Mariner 9's close-up pictures. Carefully selected photographs highlight separate chapters that describe different features of Mars. Photographs compare similar views of Mars and Earth.

Mars as Viewed by Mariner 9 (1974), NASA Special Publication SP-329, U.S. Government Printing Office, 225 p., price $8.15. A detailed "picture book" of Mars as seen through the cameras of Mariner 9, this document contains several hundred captioned illustrations of the craters, volcanoes, canyons, dunes, clouds, and ice caps that make Mars a complex and fascinating planet, partly like Earth and partly like the Moon.

Hoyt, W.G. (1976), *Lowell and Mars*, Tucson, University of Arizona Press, 376 p., price $13.95 hardbound, $8.50 paperback. A detailed and scholarly biography of the astronomer Percival Lowell and his involvement in the controversy over the existence of intelligent life on Mars. For people interested in the history of astronomy and the study of Mars in the early 20th Century.

Mutch, T.A., R.E. Arvidson, J.W. Head III, K.L. Jones, and R.S. Saunders (1976), *The Geology of Mars*, Princeton, N.J., Princeton University Press, 400 p., price $35.00. A graduate-level textbook on the surface features, geological processes, and rock formations of Mars as determined from spacecraft observations. (There is a brief appendix containing early Viking results.) The book provides a detailed scientific summary of our current knowledge about Mars. It also provides good comparisons of how the same geological forces . . . volcanoes, wind, and water . . . operate in different ways on the Earth, Moon, and Mars.

Veverka, J. (1977), "Phobos and Deimos," *Scientific American*, Vol. 236, No. 2, February, 1977, pp. 30–37. A description of the two tiny moons of Mars, revealed in close-up photographs taken by the Mariner and Viking spacecraft. The moons may be captured asteroids. They give us an indication of what millions of other small bodies in the solar system may be like.

Viking Results

"Mars: Our First Close Look," *National Geographic*, Vol. 151, No. 1, January, 1977, pp. 2–31. Handsomely illustrated presentation of Viking results for the general reader. Scientific results are combined with beautiful color panoramas of the surface of Mars.

Young, R. S. (1976) "Viking on Mars—the First Months," *NASA Report to Educators*, Vol. 4, No. 4, December, 1976, pp. 1–5. To obtain write Educational Programs Division/FE, National Aeronautics and Space Administration, Washington, D.C. 20546.

Two technical summaries of the Viking scientific results are:

Young, R.S. (1976), "Viking on Mars: A Preliminary Survey," *American Scientist*, Vol. 64, No. 6, November-December, 1976, pp. 620–627.

Viking 1: Early Results, (1976), NASA Special Publication SP-408, U.S. Government Printing Office, 67 p., price $2.00.

Technical articles on all aspects of Viking science, written by the scientists themselves, have appeared in the following issues of the magazine *Science*, published by the American Association for the Advancement of Science:

27 August 1976, Vol. 193, No. 4255, pp. 759–815.
1 October 1976, Vol. 194, No. 4260, pp. 57–105.
17 December 1976, Vol. 194, No. 4271, pp. 1274–1353.

Experiments and Activities

1. Geography and Mission Planning.

The following are the Martian latitudes and longitudes of locations that were considered as possible landing sites for the Viking spacecraft:

Latitude	Longitude	
22° N.	48° W.	(Viking 1 landed near here.)
20° N.	108° E.	
44° N.	10° W.	
46° N.	110° W.	
46° N.	150° E.	(Viking 2 landed near here.)
7° S.	43° W.	
5° S.	5° W.	

If MASA (the Martian Aeronautics and Space Administration) sent spacecraft to land at the same latitudes and longitudes *on Earth*, where would each one land? What hazards would be encountered? What would happen to the spacecraft? What would the spacecraft see? Would it detect water? life? intelligence?

If you were working for MASA, what sites would you pick for a landing on Earth? Why? For each site, identify the hazards that your spacecraft lander would have to survive. What would you expect to find? Find some pictures of the Earth from space to examine for interesting locations.

2. Retrorockets

Demonstrate the retrorocket principle by attaching a balloon to a wooden block and sliding the block down an inclined plane. Determine the velocity from the length of the plane and the time it takes the block to slide down it. Repeat the same experiment, letting the inflated balloon expel air in the direction that the block is moving (i.e., "downhill"). Show that this arrangement slows the block down, just as retrorocket motors slowed down the Viking Landers. Turn the block around so that the balloon expels air in the "uphill" direction as the block slides down the plane. Calculate the amount of velocity added to (or subtracted from) the block by the action of the balloon in each use.

3. Life Detection

Carry out simple versions of the Viking life detection experiments by making chemical tests for the presence of life in terrestrial soils. An apparatus to detect carbon dioxide (CO_2) or water (H_2O) given off by organisms in the soils can be made by connecting two bottles with a U-tube. Place a sample of organic-rich soil in one bottle. (Use commercial peat if no suitable soil is available.)

To detect CO_2, place a limewater solution in the other bottle. The end of the U-tube should be placed about 10 mm (1/2 inch) above the surface of the limewater. Any CO_2 given off will react with the limewater to produce a cloudy or milky appearance. (Try using a photographic light-meter to measure

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how rapidly the limewater turns cloudy.)

Although water in the soil may not be produced by organisms, its presence indicates the possibility of life. Water given off by the soil can be observed by using a commercial drying agent, like "Indicating Drierite" or cobalt chloride paper, instead of limewater. The drying material can be placed either in the U-tube or in the second bottle. Water can be detected by weighing the drying material or by noting the change in color.

In experimenting with heating the soil, low heat should increase organic activity and should cause a faster evolution of CO_2 or H_2O. Too much heat will kill the organisms and stop gas production. In addition, test a "control sample" that has been sterilized by heating the soil bottle in boiling water, and observe the difference in behavior.

4. Wind Erosion

Experiment with making wind-produced landforms by blowing an electric fan (or hair dryer) over a large shallow box filled with loose sand. Vary the force of the wind, the distance of the fan from the sand, and the angle at which the wind strikes the surface. Try to duplicate the sand dunes and ripples seen in Viking pictures of the Martian surface.

Place rocks on the sand surface, and try to duplicate other features seen on Mars: wind-scour under rocks, trails of sand on the downwind side of rocks, and sand deposits on top of rocks. How can these features be used to determine the wind direction? Reverse the direction of the wind, and see how much wind force is needed to change these wind features so that they indicate the new wind direction. Do wind features on Mars necessarily indicate the *present* wind direction? Try making and studying 3-dimensional stereo photographs of your artificial wind features. (See Experiment #5.)

5. Stereo Photography

Demonstrate how three-dimensional stereo pictures, like those produced by the Viking cameras, are made and used. Take one picture of a scene (e.g., a classroom), move the camera 2–3 feet sideways, and take another picture of the same scene. Examine the two pictures with a stereoscope, moving them until the picture is seen in three dimensions. Make sketches and maps of the scene, indicating objects that are high and low, near and far. A print-making color camera is convenient, but any camera can be used.

If you use a color camera, you can demonstrate how the Viking cameras produce color pictures by combining photographs taken through different color filters. Experiment by placing colored filters (of glass or plastic) in front of the camera lens before you take the picture. Wratten gelatin filters are best: number 47B (blue), 29 (red), 61 (green). Colored acetate can also be used; it is cheaper, but it will distort the image somewhat. Take each picture in a stereo-pair through different colored filters, then "combine" the colors by viewing the stereo-pair with the stereoscope. Which pair of color filters produces the best match with the colors in the original scene? Are two colors adequate to make a good match?

6. Magnetic Material in the Soil

Make a synthetic "Martian soil" by mixing about 5 percent of magnetic material (crushed magnetite, Fe_3O_4, or iron metal filings) with clean white sand. Using a large bar or horseshoe magnet, try various methods of collecting this magnetic material from the soil, e.g., scraping the magnet through the soil, pouring the soil over the magnet, or spreading out the soil in a thin layer and passing the magnet over it. First wrap the magnet in paper or plastic film so that you can easily remove the magnetic material that adheres to it.

Examine the collected material with a hand lens or a low-power microscope. How much white nonmagnetic sand was collected with the dark magnetic material?

Prepare a soil sample that contains a known weight of magnetic material. Try various collection methods and weigh the amount of magnetic material collected in each way. Calculate the *efficiency* of each method, i.e., the weight collected divided by the weight originally present. Discuss why some collection methods do not approach 100 percent efficiency.

Make up several soil samples with varying amounts of magnetic material, e.g., 1, 5, 10, and 25 percent. Process each sample with the most efficient collection method, and weigh the amount of magnetic material collected. Calculate the total amount of magnetic material present, knowing that: (amount present) = (amount collected) / (efficiency). Repeat the experiment a few times. How reproducible are your results? How accurate are they?

Substitute a different magnetic material (iron metal filings for magnetite or vice versa) and repeat the experiments. Does the efficiency of the collecting methods change? Why?

7. Mechanical Properties of the Soil

Study how the mechanical properties of different soils affect the appearance of trenches dug in them. Make a series of soil samples by mixing loose sand with varying amounts of fine clay or chalk powder.

Experiment on mixtures that contain zero percent clay (pure sand), 25 percent, 50 percent, and 100 percent clay (pure clay).

Make trenches by sticking a ruler into the soil and pulling it through the soil sample. Note the appearance of each trench, and describe what happens to the walls after the trench is formed. What percentage of clay is needed to form a steep-walled trench like those in the Viking pictures?

Pour a sample of each soil onto a flat surface from a height of a few centimeters. Note how the piles differ in smoothness, in slope, and in the number and size of clumps formed by the soil.

Is there any difference in behavior between the soil that has 25 percent clay and the soil that is pure clay?

Examine the Viking pictures of the trenches dug in Martian soil. Does the Martian soil behave like loose sand? Which soil sample best duplicates the behavior of the Martian soil?

Study the effect of water by sprinkling a little water on the surface of the soil sample before digging the trench. Through which soil does the water move fastest? How does the water affect the shape of the trench in each soil?

8. The "Canal" Illusion

On a white sheet of paper about 2 feet by 3 feet in size, draw a random arrangement of dots, circles, ovals, straight lines, wavy lines and irregular smudges. Make sure that the diagram is a completely random pattern. Hang the paper at the front of the classroom so that it is well-lit, and have the students draw what they see.

Compare the drawings by students who are closest to the diagram with those by students who are further away. Which ones reproduce the pattern best? How many in which group draw straight lines where none are present in the picture?

(This experiment was first performed many years ago by the astronomer Maunder to demonstrate the eye's tendency to produce imaginary lines to connect objects that are entirely separate but poorly seen.)

9. Mars in Fact and Fiction.

People have often commented that science-fiction literature often predicts future facts and developments. (Jules Verne's *From the Earth to the Moon*, and *20,000 Leagues Under the Sea*, are often cited as examples.)

Science-fiction has been written about Mars for more than three-quarters of a century. A partial list of books, all available in paperback, is:

H.G. Wells, *The War of the Worlds* (1898).
Edgar Rice Burroughs, *A Princess of Mars* (1912).
C.S. Lewis, *Out of the Silent Planet* (1944).
Robert A. Heinlein, *Red Planet* (1949).
Ray Bradbury, *The Martian Chronicles* (1950).
Arthur C. Clarke, *Sands of Mars* (1952).

What conditions of temperature, atmosphere, and climate did the various authors attribute to Mars? What kinds of Martians lived in these conditions? How did Earth people adjust to Mars, and Martians to Earth? Did the authors' view of Martian conditions change as we learned more about Mars? How accurately did the authors predict the real nature of Mars as we have determined it from Viking and other spacecraft?

How would you write an "accurate" science-fiction novel based on the view of Mars revealed by Viking? What kinds of "Martians" could exist? What protection would humans need on the surface of Mars? What hazards would humans on Mars face from natural processes or from "Martians"?

Suggested Viewing

A series of four films produced by NASA discuss the planet Mars and the Viking life detection experiments. The films, produced before the Viking landings on Mars, may be borrowed from NASA Regional Film Libraries without rental charge.

Life?
HQ 261—COLOR—14½ MINS.
General characteristics of life are first described with non-life similarities noted. A number of adaptations are included to show how life has adapted to Earth conditions, and how certain individuals can withstand environmental insults. In conclusion, the habitat of Mars is described with the question raised as to the possibility of life existing there.

Mars—Is There Life?
HQ 263—COLOR—14½ MINS.
Students are introduced to the possible past history of Mars, as well as its present surface topography—from volcanoes, ice caps, stream beds, impact craters, canyons and wind-eroded surfaces. The Viking lander and its biology experiments are discussed in relationship to the search for life on Mars. In conclusion, students are asked to consider life forms that might be able to survive on Mars, and the potential significance of their discovery.

Mars and Beyond.
HQ 264—COLOR—14½ MINS.
This film traces the Viking mission to Mars to specifically explore the biochemical evidence of life. Elementary chemical components of life (as we know it) are introduced; these are related to the organic analysis instrument on board the Viking lander. The instrument is described by design and operations. The program concludes with the potential significance of biochemical findings—how they may relate to past, present and future Martian life.

A Question of Life
HQ 270—COLOR—28½ MINS.
The film is a composite version of three 15-minute films: *Life?* (HQ 261), Mars: *Is There Life?* (HQ 263) and *Mars and Beyond* (HQ 264). A definition of life and general conditions necessary to sustain life are discussed. Viewers are introduced to the possible past history of Mars as well as its present surface topography and its capacity to support life as we know it. Major emphasis is placed on the Viking life detection experiments including the three biology experiments and the organic analysis instrument. Consideration is given to the potential significance of discovering life elsewhere in the universe.

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